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Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 226 AUGUST, 1938 No. 2

LIGHTHOUSES IN THE SKY
OR
NAVIGATION AT SEA.*

BY

GEORGE W. MIXTER,

Vice President, Day & Zimmernann, Inc., New York.

"Lighthouses in the Sky," the title of this discussion of navigation, suggests both the mystery which seems always to have surrounded the work of the navigator and the simplicity of the principles which have made possible that movement of vessels over all the oceans without which the present civilization of our world could not exist.

One cannot teach navigation in an evening, although the technique of the art consists of skill with a few apparently simple tools and a little arithmetic wherein the principal problem is to know whether to add or to subtract. Neither can the great Bowditch and all the other books do more than teach principles and methods and point out the errors against which one must guard. Only knowledge *with practice* and *an ever alert mind* can make one competent to navigate either small or large craft along the coast or at sea. Nevertheless, those of you who are not navigators may understand the modern conception of the old principles which guide ocean-going vessels.

* Presented at a meeting held Thursday, February 24, 1938. Copyright, 1938 by George W. Mixter.

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Broadly speaking, navigation is the art of directing the course of ships in any waters. The subject is commonly divided into three parts: Piloting, dead reckoning and celestial navigation.

Piloting is the art of conducting vessels along coasts and in and out of bays and harbors, where landmarks and aids to navigation are available. Captain Dutton characterizes piloting as requiring the greatest experience and nicest judgment of any form of navigation. Mistaken identity of a light or some apparently slight error in the course or distance made good, may wreck the ship, whereas at sea an error in position may be corrected by later observations.

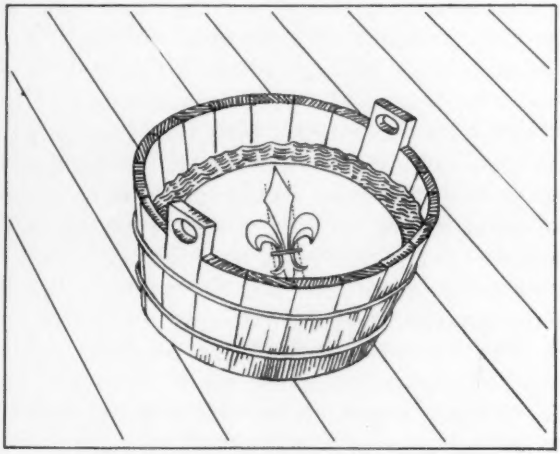
Dead Reckoning, I am told, was originally called "deduced" reckoning, thence abbreviated D-E-D; or in the vernacular DEAD reckoning. It is an element both of piloting and of navigation at sea. As used in modern navigation, it is the process of finding the approximate position of the ship by plotting the courses and distances from the last well-known position, which may have been determined from navigational marks along the coast, or from observations of the sun, moon or stars. This sounds simple, but for various reasons such positions may be inaccurate. Therefore when piloting, the D. R. positions are corrected frequently from bearings of known landmarks; at sea a correction may be made whenever both the horizon and one or more brighter heavenly bodies are visible.

Celestial Navigation, which is our principal subject this evening, is the art of checking or fixing the position of the ship from observations of so-called navigational bodies which include the sun, the moon, four of the planets, and the principal stars. These are the Lighthouses in the Sky.

Up to the time of the Portuguese exploring expeditions sent out by Prince Henry, known as The Navigator, beginning with the discovery of the Azores in 1419, navigation was conducted in a most uncertain manner. Prince Henry, however, collected the then existing knowledge of nautical affairs and founded an observatory, near Cape St. Vincent, to determine the astronomical data required by navigators. Succeeding centuries have witnessed progressive development of those elements of astronomy, mathematics, geography, chart making

and instrument design which concern "pilots," as navigators were called in Prince Henry's time.

Columbus had a compass, presumably with its needle on a pivot rather than floating in a tub, an astrolabe and a cross staff, a fairly good table of the sun's declination, a correction for the altitude of the North Star and probably a globe. He could approximate latitude by the same general methods as now used, but the mystery of finding the longitude at sea remained unsolved for about three hundred years.



MARINER'S COMPASS – CIRCA A.D. 1200
As described by Capt. John Gorett and by W. Findlay Downs who examined this compass in a Warsaw museum in 1908 and in 1926

From 1600 to 1700, charts constructed on Mercator's projection, as are most of those used today, came into use. Napier's invention of logarithms went far to facilitate the navigator's calculations; and the accuracy of observations at sea was increased by Vernier's device and the use of the tangent screw. Continued efforts to determine longitude were without practical success, although that celebrated problem of finding longitude by the method of lunar distances occupied attention of astronomers and navigators.

The advent of the sextant in 1731 often is described as marking the beginning of modern navigation. Previously, all instruments for measuring angles at sea depended upon the plumb line as does the astrolabe, or required the observer to

look in two directions at once, as with a cross-staff. The sextant's most important function is to measure angles of altitude above the sea horizon. Because of its small dimensions, its accuracy, and, above all, the fact that it does not require a stable mounting, a sextant peculiarly is suited for use under conditions existing on shipboard. With the compass and the chronometer it shares the honor of being one of the three instruments that have made modern navigation possible.

The sextant's invention most commonly is ascribed to Hadley, an English country gentleman, assisted by his brother who was a barrister. However, at the same time, an instrument of similar principle was invented and built here in your City of Philadelphia by one Thomas Godfrey, a glazier of repute. Watson's Annals of Philadelphia suggest that Hadley pirated Godfrey's invention, but the generally accepted opinion is that each man independently invented the sextant.

At about the same time, many minds were competing for the prize of £ 20,000 offered about 1720 by the British Government "for the discovery of longitude at sea." Many suggestions were submitted, but the problem reduced itself to the determination at sea of Greenwich time, by one of two methods: The Astronomer Royal of England contended for the method of lunar distances, while Harrison and others strove to produce timekeepers which would function accurately aboard ship.

In 1775, Harrison's chronometer was finally awarded all of the prize of £ 20,000, and longitude was "discovered." But, as late as 1794 a captain out of Salem was reprimanded for having bought a chronometer—an impertinent extravagance, since the cost of the chronometer may have equaled the crew's wages for the entire voyage. In fact, there elapsed fifty years, more or less, before the comparison of Greenwich time obtained from chronometers and local time obtained from observations became the accepted basis for determining longitude.

Another date of historical interest to navigators is marked by the first publication of Nathaniel Bowditch's "American Practical Navigator," at Newburyport in 1802. This special abomination of every novice, periodically revised by the Hydrographic Office, continues today as the epitome of navigation of our United States Navy and Merchant Marine.

Although confusing as a textbook, it remains almost a necessity for every navigator because of its infinite information and its tabular data.

An annual publication necessary to all navigators is the Nautical Almanac which, in its American form, first was published by our government for the year 1855. The United States coöperates with Great Britain, France, Germany and Spain in exchange of data used in preparation of the various Almanacs.

Thus, during the last century, with the sextant, the chronometer, Bowditch and the Almanac, there was developed a system which sometimes is called the *old navigation*. Dead reckoning was computed or reckoned by trigonometry and logarithms rather than found by plotting courses and distances on a chart. A morning time-sight of the sun gave a point of position which was correct only if an assumed dead reckoning latitude was correct. The noon-sight gave true latitude but longitude of noon position was correct only if course and distances from morning position were accurately known. Perhaps our skipper took an afternoon time-sight, again to check his longitude. Star sights were well understood but less used than at present. These methods continue to be widely used in the Merchant Marine and, although called the *old navigation*, are susceptible, at least in principle, of as great accuracy as are the newer methods.

Since about 1900 there have come into prominence certain changes, not in the fundamental principles of navigation but in their interpretation and in methods of utilizing old principles. These developments sometimes are called the *new navigation*, which now is the accepted practice of the navies of the world and of most yachtsmen, and is superseding traditional methods of the merchant marine. This so-called new navigation had its genesis almost exactly one hundred years ago, on November 25, 1837, in the discovery by Captain Thomas H. Sumner, an American shipmaster, that a single observation, taken at any time, sufficed for determining a line on the chart somewhere on which the ship must be. This is the line of position or Sumner line which is the very essence of modern practice. I like to call them "Sumner" lines, partly because it is a short name which refers only to lines of

position at sea, but principally in honor of old Captain Sumner who thus made the greatest advance in navigation since the chronometer was perfected.

We must now go forward with our principal problem of this evening, namely: to explain how the navigator actually does his work at sea. Beforehand let me repeat that time permits me only to give you a picture of the general methods of celestial navigation. The technique of using the various instruments and tables will not be discussed, and no attempt will be made to interpret possible errors therefrom, both of which are inescapable necessities in actual practice of the art. Navigators need not, and in most cases do not, understand either spherical trigonometry or such theories of astronomy as underlie the methods he uses.

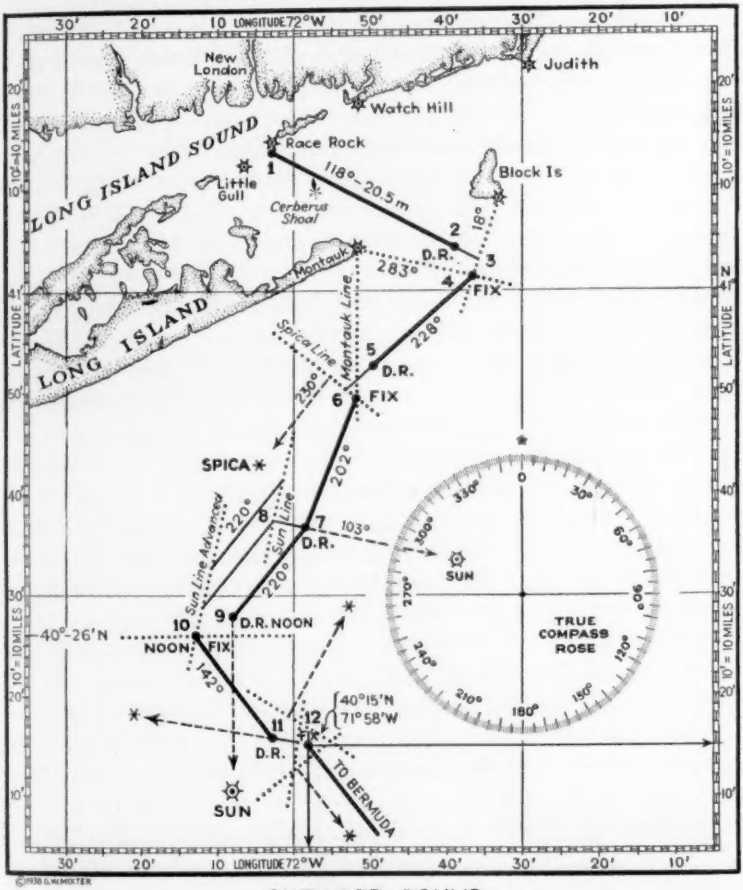
OUTWARD BOUND.

Before discussing celestial navigation, let us follow, as an example, a vessel outward bound from the eastern end of Long Island Sound; and thus develop certain methods and definitions common to all navigation. The vagaries of courses and distances used to facilitate our illustration may be accounted for by assuming the vessel to be a sailing yacht subject to shifting winds or calms and to tidal currents which play the devil in these waters. Cerberus Shoal is well named.

In the language of piloting our navigator observes that his ship is one mile true south of Race Rock Light and he marks this position at (1) on the chart. The direction sailed from that point is shown by the course marked 118° which is a direction measured by or transferred from the true compass rose, with the aid of parallel rulers. With such rulers a line parallel to his course may be drawn from center of compass rose, and its true direction may be read from the scale around the rose.

Most of you know that the magnetic compass seldom points true north. In Block Island Sound it points more than 13° west of north and the yacht sailor in these waters would define our initial course as SE½E magnetic. However, magnetic compass readings can be corrected to true and *vice-versa*. This evening, in the interest of simplicity, we will work only with true directions expressed in degrees and as measured by the true compass rose.

From the point of departure marked (1) the ship proceeds, along the 118° course, 20.5 nautical miles. Distance through the water may be measured by the so-called patent log. Miles on the chart are measured by scales of minutes of latitudes at sides of chart, because one minute of latitude is a



OUTWARD BOUND

measure of a nautical mile. With this scale of miles, our navigator measures 20.5 miles from (1) and thus plots the so-called dead reckoning position at (2). This is simple enough, but the position so found is seldom accurate. The point of departure may have been in error, steering may have

been inaccurate and, in these waters, the best of pilots cannot estimate exactly the effect of tidal currents.

Therefore, the only safe assumption is that the ship is not at the D. R. but elsewhere. Under unfavorable conditions it may be many miles away.

Fortunately, especially at night, it is easy to check and correct this D. R. position, marked (2). The great light known as Block Island Southeast flashes green every few seconds and, with aid of ship's compass, our navigator notes that the direction or bearing of the light from the ship is about 18° true. You should remember that the position of the ship is uncertain but that the position of this man-made lighthouse is known to be exactly where it is marked on the chart. Therefore, with parallel rulers, take an 18° direction from the compass rose and draw a line through the lighthouse on the chart. This then is a *line of position*, shown by dots, somewhere along which the ship must be.

Mark you that this single observation of the bearing of Block Island Southeast gives only a line of position and does not tell you where you are on that line. Lacking another observation, the best estimate of our ship's position would be at (3) where the course intersects the Block Island line. However, Montauk is flashing white every 10 seconds and bears about 283° from the ship. A line in this direction through Montauk is also a line of position and the ship must be somewhere along this line.

Assuming the two bearings to have been taken practically simultaneously, we know that the ship is somewhere on the Block Island line and somewhere on the Montauk line and therefore must be at that point where the two lines of position intersect. Such a point determines the position of the ship and is known as *a fix*.

In this way, the D. R. position at (2) has been corrected to the fix at (4) from which we shall assume that the ship proceeds on a course of 228° to the D. R. position marked (5). Block Island Southeast is no longer visible, but Montauk can be seen bearing almost exactly true north. With this information, a single line of position is drawn; but no other land-lighthouse is visible from which a second line of position can be had for a fix.

In fact, our skipper is almost out of sight of land and must use the *Lighthouses in the Sky* which, as I have explained, are: the sun, the moon, four planets and the brighter stars.

Whenever an accurately timed altitude of any of these bodies can be had, a line of position may be plotted with considerable accuracy. Such lines of position, often called Sumner lines, are at right angles to, and thus square across direction or bearing of body observed, and in this way differ from lines representing bearings of land lighthouses. In either case a single observation gives only a line of position and does not give position of ship other than at some undetermined point on the line.

Now let us return to ship at D. R. position marked (5). The bearing of Montauk has been plotted and at about the same time the navigator observes a first magnitude star, Spica, and therefrom plots another line of position which is the Spica line at right angles to the bearing of the star as shown on chart. The intersection of the two lines is a fix at (6).

From this point the ship sails to an estimated D. R. position at (7), when our navigator observes the sun which bears about 103° to the eastward. A resulting sun line (8), would indicate that the ship was about 3 miles west of its D. R. position. Thereafter conditions may have dictated a change in course along which the ship sails until the traditional noon sight of the sun bearing true south gives a line of position which is the parallel of latitude 40° 26′ N.

To obtain the customary noon fix, with parallel rulers the navigator moves forward the sun line marked (8) by the course and distance estimated to have been made good from D. R. (7) to D. R. (9). The sun line thus advanced intersects the noon sun line at the point which is the noon fix marked (10).

From the noon fix a shift of wind and light air has resulted in a course of 142° for a distance of only 13 miles to the D. R. marked (11) at evening twilight. A skillful navigator, knowing in advance those stars which best would serve his purpose, will observe three stars at almost the same time.

The resulting three lines of position gave a fix within a triangle. Theoretically, any three lines of position, deter-

mined from observations taken simultaneously, should intersect at a point. Practically, results as shown are excellent and the resulting fix may be considered accurate.

The position of this fix, in the language of navigators at sea, may be found by extending an horizontal line to latitude scale at side and a vertical line to longitude scale at bottom of chart. Readings of these scales, at ends of lines so drawn to the points marked with arrows, give position of ship at time of three star fix as 40° 15′ N. and 71° 58′ W.

We now have reviewed the general character of the work the navigator does on his charts or plotting sheets. An important point to remember is how lines of position are used continually to check position of ship. Our next step is to develop the method of determining necessary position lines, or Sumner lines, when out of sight of land.

THE CELESTIAL SPHERE AND THE EARTH.

The Celestial Bodies, of which there is a vast and unknown number, are distributed throughout an infinitely great universe and include the earth, and the various bodies observed by mariners. The earth is assumed to be at the center of the universe, and all other celestial bodies, regardless of their enormously varying distances from earth, appear as upon the great dome of the heavens, or as upon the inner surface of the hollow ball called the celestial sphere.

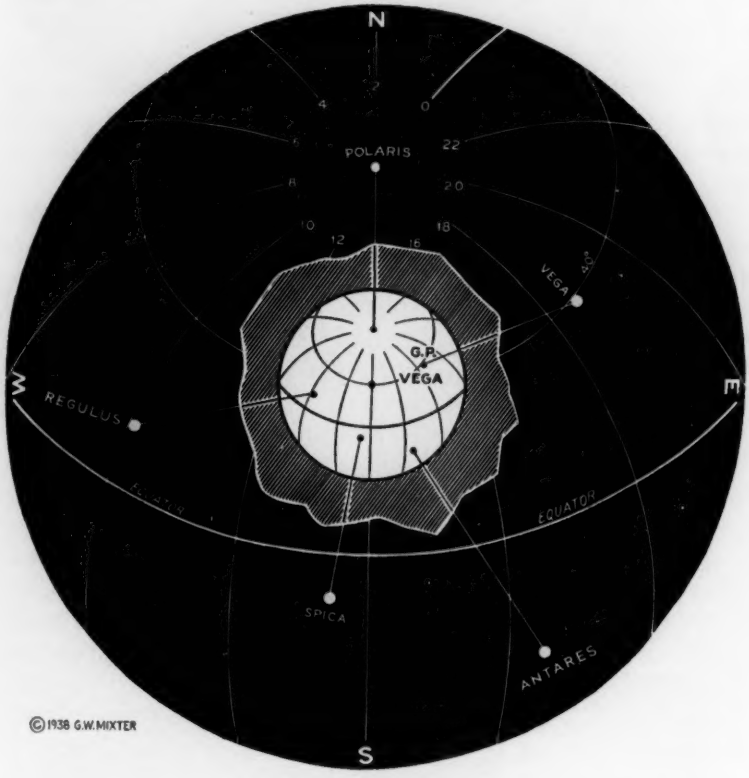
What the relationship of this imaginary sphere is to the earth is suggested by the picture now on the screen which necessarily shows earth as too large and surrounding celestial sphere as far too small. Poles and equator of celestial sphere are always directly over those of the earth, and the axes of the spheres coincide. Center of earth is the center of the astronomical universe. The ship is on the surface of the earth; all of the navigational bodies are on the celestial sphere. This conception of two spheres is important.

LIGHTHOUSES IN THE SKY.

On a clear, dark night, look carefully at the stars directly overhead and also at those near the eastern and western horizons. The 10 P.M. star map is a picture of the celestial

sphere at this moment, as if you were looking down upon it from directly above the City of Philadelphia.

Note Polaris at (1), often called the North Star, almost at north pole of celestial sphere; and also note the Dipper. If, for a moment, you descend to earth and look up you will find



THE CELESTIAL SPHERE AND THE EARTH

Pollux overhead at (2). Arcturus, marked (3) is near the eastern horizon but north of the equator.

The midnight map shows the stars two hours later: Pollux at (2) has moved 30° to the westward; the stars previously seen near the western horizon have set, and are no longer visible; Arcturus is higher in the east at (3). The entire celestial

sphere appears to rotate, and all celestial bodies overhead appear to move from east to west, and to rise and set once each day.

Thus if you were star gazing at two o'clock this morning you would have seen Pollux and Arcturus still farther to the west at (2), and at (3), and great Vega would be visible at (4).

Or if you will look at the sky tomorrow morning at 4 A.M. Pollux will be just above the western horizon and Vega will dominate the eastern sky. Although I suspect that none of you will look upward at such an hour, it is the time when the navigator should prepare for his morning sights.

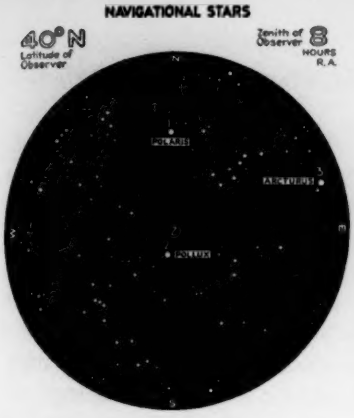
The 6 A.M. map shows the stars at morning twilight when both the bright stars and the horizon are visible. The stars remain in almost fixed relations to each other on the apparently rotating celestial sphere. The sun, the moon, and the planets continually change their positions among the stars, although in bright sunlight the stars are invisible.

At 8 A.M. the sun has risen and is shown starting its daily journey, westward, across the heavens.

The apparent motion of the stars is most simple, although the stars overhead at a given hour of the evening change throughout the year. The sun takes about 4 minutes longer to appear to move around the earth than do the stars, and, unlike the stars, the sun moves from north to south and back again once each year. The moon changes its position more rapidly than any of the other bodies. The apparent position of planets is most irregular.

Were we further to amplify our sketch of the universe, and discuss the actual motions of heavenly bodies, it would emphasize that the navigator deals with four quite different types of Lighthouses in The Sky whose varying apparent positions over the earth are caused by their own motion and/or the motions of the earth.

In order to use any one of these continually moving navigational bodies as a lighthouse, it is necessary to know exactly where the lighthouse is at the instant it be observed for a line of position. For the navigator, who need not deal with complications of astronomy, this is a simple matter.



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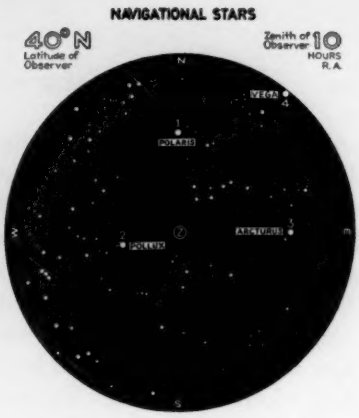

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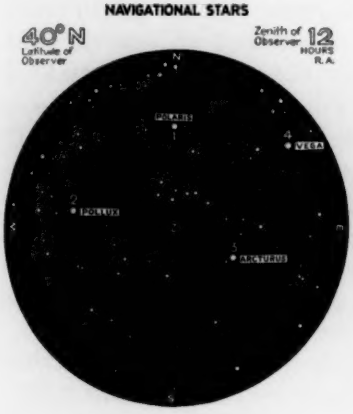
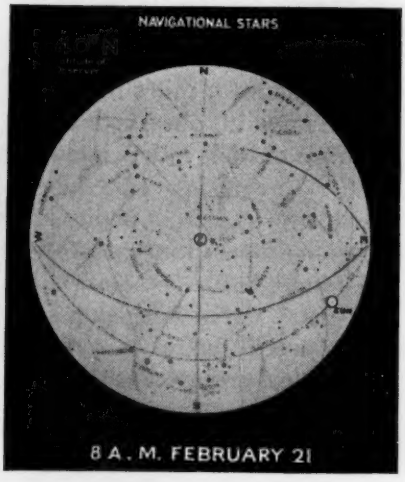


2 A. M. FEBRUARY 21

4 A.M. FEBRUARY 21

6 A.M. FEBRUARY 21
MORNING TWILIGHT



8 A. M. FEBRUARY 21

Study the star Vega shown in upper right of drawing, titled The Celestial Sphere and the Earth. From Vega, drop a plumb line to the center of the earth, and mark the point where the line intersects the earth's surface at the geographical position of Vega, or G. P. Vega. Expressed otherwise: this is the sub-stellar point or the point on the earth directly under Vega at a given time. If you know this instant of time, then the latitude and longitude of this geographical position may be taken from the Nautical Almanac. This morning, at exactly 4 A.M. E. S. T., February 24, 1938, the geographical position of Vega was in 38° 43′ N. latitude and 9° 52′ W. longitude. This is all you need to know about Vega in order to lay down a line of position; assuming, of course, that conditions of visibility permit your observing the altitude of this star above the horizon.

Thinking of the apparent position of a navigational body as a point on earth is not a new conception, but in my judgment, this idea has not been emphasized sufficiently when teaching navigation. Tonight, we shall talk about G. P. Sun, G. P. Vega, G. P. Rigel, and so on. Look again on the screen and try to realize how truly the geographical position of Vega defines its position as related to the earth.

In order to determine geographical position of a navigational body at the instant it be observed, the navigator must have available two most important tools of his trade.

Time of an observation is determined by aid of one or more *chronometers*, large watches hung in gimbals, whose errors may be noted from day to day from radio time signals. In this latitude (40° N.) an error of 1 minute of time will cause an error of about 9 miles in the east-west position of ship.

Position of observed body is taken from the *Nautical Almanac*, which must, incidentally, be the edition published for the current year; because, for a given date and time, the position of celestial bodies varies from year to year. This especially is true in the case of the moon and the planets which, accordingly, are not shown on any permanent maps of the heavens. Details of using chronometer and Almanac cannot be discussed tonight but are important elements of technique in practical navigation.

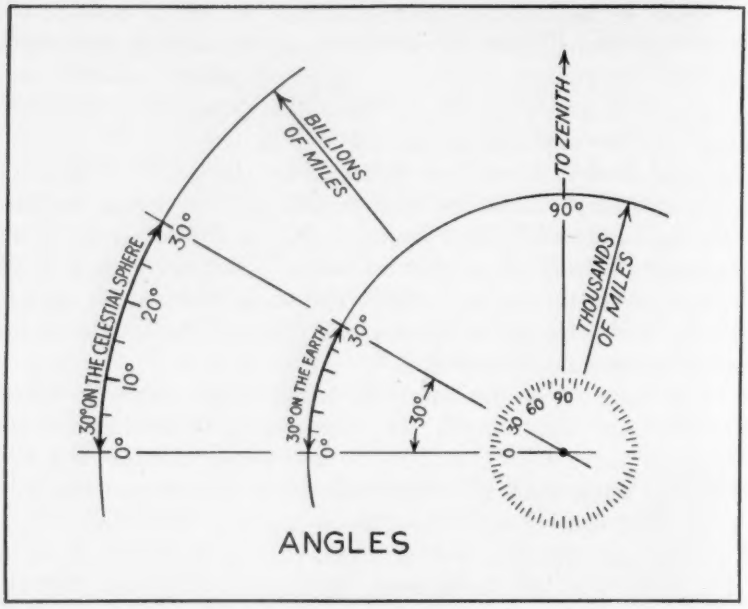
Again let us refer to the drawing. We know that at the given instant of time, the position of the point on the earth exactly under Vega, known as its geographical position, was in 38° 43′ N. and 9° 52′ W. This defines apparent position of Vega in the same language by which the last fix on our Outward Bound chart was defined, i.e., in terms of latitude and longitude. A professional would use the terms declination and Greenwich hour angle, as in the Almanac, to define apparent position of a celestial body. But never you mind, because these terms are exactly the same in meaning and of exactly the same value as the latitude and longitude of the body's geographical position.

The drawing shows only four other stars: Antares, Spica, Regulus and Polaris. If the star map of this half of the celestial sphere were complete, as previously shown for 4 A.M. February 21st, some 18 additional navigational stars could be seen. The sun is just around the corner and will rise in about three hours. In this year of 1938, the moon would show on map slightly to left of Antares, in direction of Spica, but the four navigational planets are out of sight on the unseen half of the celestial sphere along with the unseen stars.

Regardless of where any of these Lighthouses in the Sky may be located, their *geographical position* for any date and instant of time may be taken from Nautical Almanac for current year. With such knowledge, whenever a timed altitude of any one of the navigational bodies can be observed, a line of position may be drawn, and the ship must be at some point on this line.

ANGLES.

Let us review the nature of angles as used throughout all celestial navigation. Remember that angles are measured by the divergence of two lines, without regard to their length. An application of this concept of an angle, which is pertinent to the succeeding discussion, is now shown. From the center of the earth, the angle between the ship and a possible star is, for example, 30°, regardless of fact that length of sides of angle may be almost infinitely different. This use of angles will be developed further in succeeding illustrations.



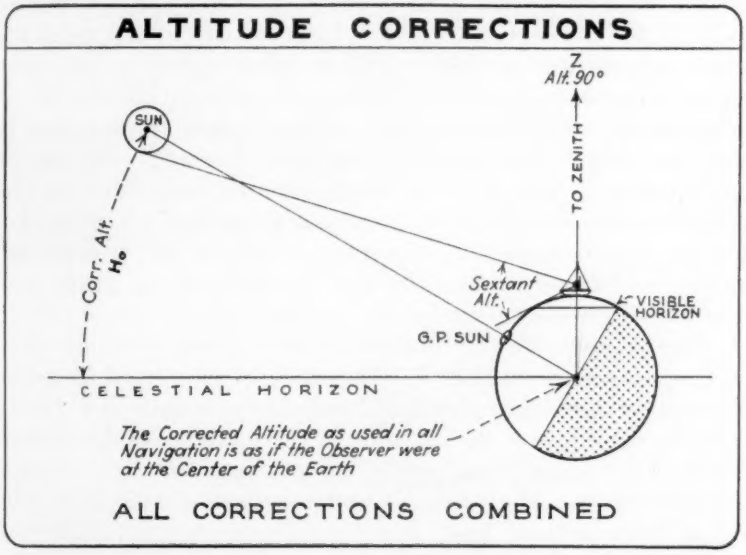
ALTITUDE CORRECTIONS.

Also, before considering methods for determining a line of position, or Sumner line, it is essential to understand that altitudes as read from the sextant must be corrected and converted into true altitudes before use in the calculations of the navigator. The nature of the required corrected altitude is suggested by the drawing. It is the true angle of altitude of center of observed body as if taken from center of earth. Succeeding drawings will indicate the necessity for using this altitude which results from correcting the sextant reading.

The sextant gives only the apparent angle of altitude of observed body above visible horizon where sky meets sea. The ocean is not flat but is a part of the spherical surface of the earth; therefore, visible horizon is lower than as if sea were level and sextant reading is too great, an error which is further increased because observer's eye is above surface of water, sometimes 40 feet or more as from the bridge of a big ship. Except with highest altitudes, the rays of light from body to sextant always are bent by refraction when passing

through earth's atmosphere, and for this reason, especially with low altitudes, the sextant reads too high. In case of sun or moon, the lower edge, called the lower limb, most commonly is observed, resulting in an altitude which is one-half diameter of body less than the altitude of its center. The correction for what is known as parallax, which gives an altitude as from center of earth, is of major importance when the moon be observed.

Despite these complications, all corrections combined may be made by adding or subtracting one or two figures taken



from simple tables, the result being the desired corrected or true altitude.

It is important to grasp the idea that correcting an altitude has the effect of transferring observer to center of earth, which also is center of celestial sphere. An easy way to understand the relative position of a body on the celestial sphere and the ship on the earth is to place yourself at the common center of the two spheres. Perhaps you object to being buried but if you think of the earth as only a cellophane globe with yourself sitting at its center, the ship may be seen in its actual latitude and longitude on the earth and the observed body will appear

as if in its geographical position, which also may be defined in terms of latitude and longitude.

An appropriate remark at this point, is that observing a reasonably accurate sextant altitude, which is a primary necessity at sea, often is not an easy matter, especially under unfavorable conditions. Personally, lack of skill with the sextant has been my greatest difficulty. The instrument itself is simple enough but its successful use requires practice and more practice.

USE OF ALTITUDES.

Our next step then is to develop how altitudes, corrected to read as if observer were at center of earth, are used for checking position of ship. The drawing shows a line from center of earth to ship on earth's surface and continued upward to the zenith which is the point on the celestial sphere directly over the ship. The imaginary celestial horizon is drawn at right angles to line through ship to zenith and therefore the altitude of the zenith above the celestial horizon is always 90°. The sun is shown with a corrected altitude of 50°, leaving 40° (90° − 50°) from the sun to zenith, or 40° from G. P. sun to a ship which is directly under the zenith.

Thus, coming down to earth, you have found distance from G. P. sun to ship to be 40°. This may be expressed in miles; because by definition a nautical mile is the length of 1′ of arc of any great circle of the earth. As there are 60′ of arc in each degree, 40° would equal 60 × 40, or 2400′ or arc, or 2400 nautical miles. You now have determined this distance by aid of your sextant and, when conditions are favorable for observing altitudes, distances so determined may be accurate within plus or minus one-half mile.

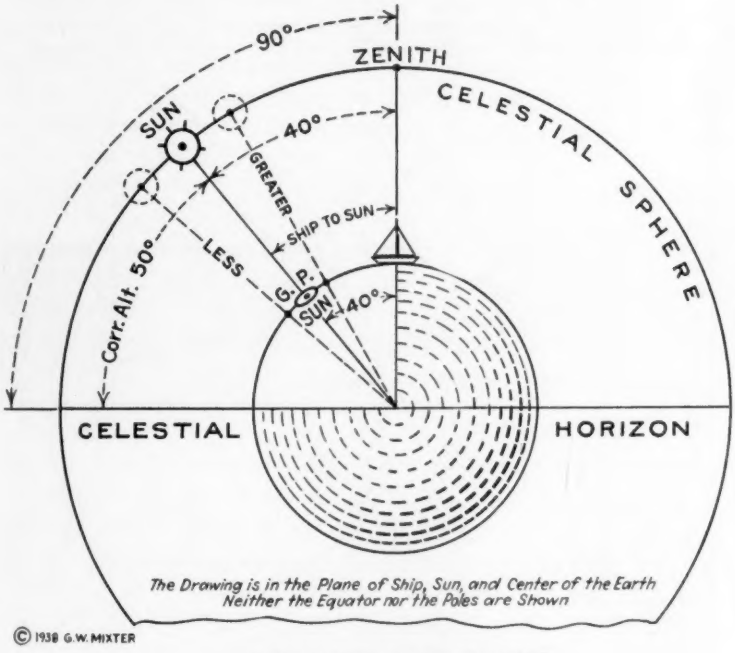
Thus far, from your observation, you know only two facts:

(1), *Position* of G. P. sun from Nautical Almanac,
and by aid of your sextant you have determined,
(2), *Distance* of ship from geographical position of sun.

Any observer, whether he be north, south, east, or west, or in any other direction from the sun, who finds same altitude, will be at same distance away from G. P. sun. You may be any one of these observers. Therefore, all that you know from a single timed observation of any body is that the ship is *somewhere on a circle of equal altitudes* whose center is the G. P.

position of the body, and whose radius is the distance from that position to ship.

Before we illustrate circles of equal altitude on a chart, again let us examine the drawing. An observer finding an *altitude less* than 50° will be more than 40° away from sun and he will be outside or *away* from the circle of equal altitudes.



USE OF ALTITUDES

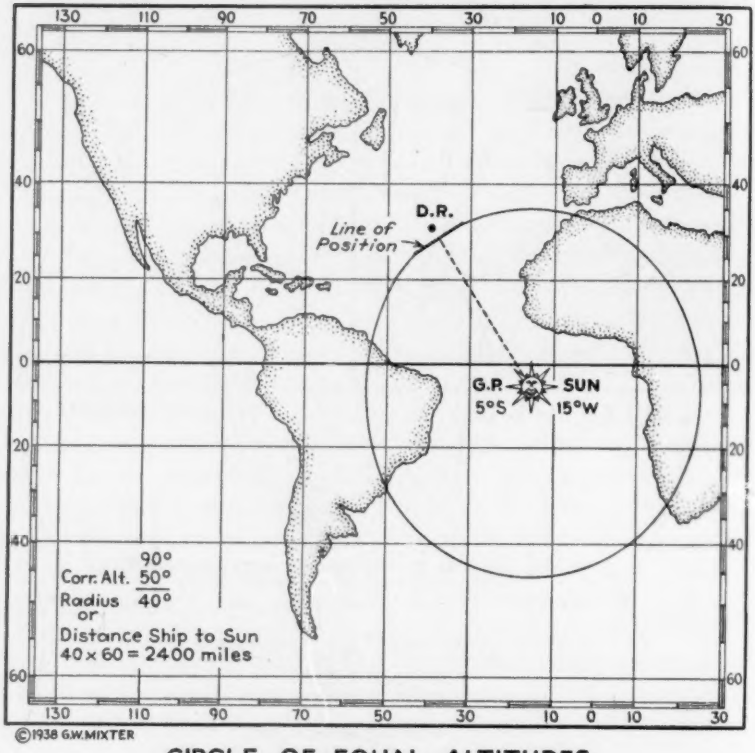
Altitude LESS
Observer further AWAY *from the Sun*

Altitude GREATER
Observer nearer or TOWARD *the Sun*

Another observer, finding an *altitude greater* than 50°, will be less than 40° distant from G. P. sun and he will be inside the circle of equal altitudes, nearer or *toward* the sun. Understanding these facts is essential when laying down a line of position as in modern navigation. Convince yourself that when the altitude is less, the G. P. sun is farther away from the ship than is the G. P. sun when the altitude is greater.

CIRCLE OF EQUAL ALTITUDES.

The chart shows a *circle of equal altitudes* of the sun. The G. P. sun on the Atlantic Ocean is 5° S of the equator and in 15° W longitude. The corrested altitude was 50° and therefore the radius of the circle, or distance from ship to sun was 40°, which, when reduced to minutes of arc, represents 2400 nautical miles. The peculiar, somewhat elliptical shape,



CIRCLE OF EQUAL ALTITUDES

is the result of plotting the circle on a Mercator chart, the kind commonly used by navigators. A globe furnishes the only correct map on which the circle of equal altitudes would appear as a true circle and as if drawn on earth itself.

The only definite knowledge obtained from the timed altitude of sun is that ship is somewhere on this circle; off Gibraltar, off the Cape of Good Hope or in any one of an infinite

number of other positions in the South or North Atlantic Oceans. However, by dead reckoning from the last fix, the navigator knows his approximate position, which may be any point within a relatively small area. With this added knowledge, he is justified in assuming that ship is somewhere on a nearby arc of the circle which is generally so short that it may be represented by a straight line tangent to the circle, and therefore at right angles to direction of sun. *This is the Sumner line* or line of position. The ship must be on this line and the D. R. position may be partially corrected, although the navigator does not know exactly at what point on the line is the position of ship.

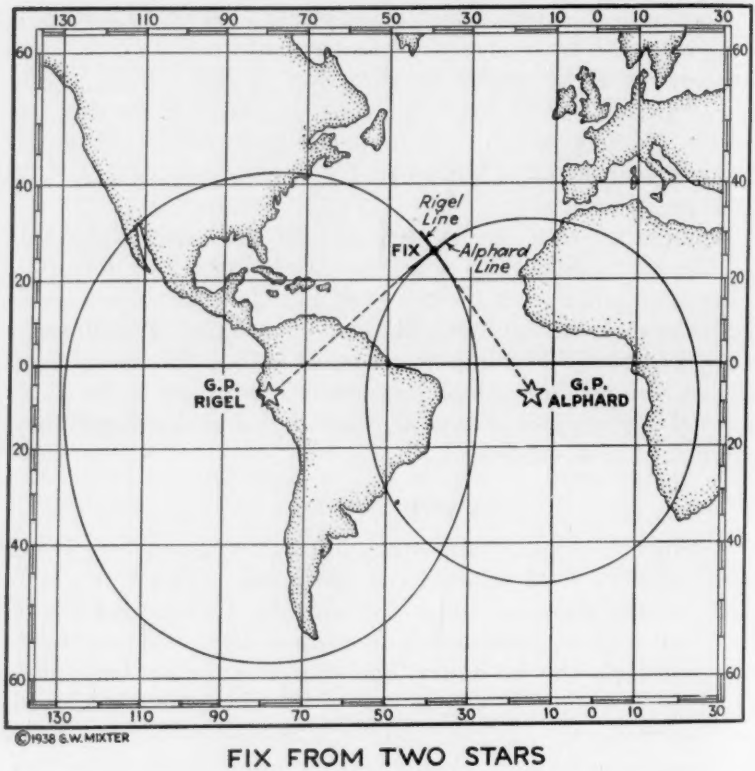
Remember that the somewhat distorted curves on this and the succeeding chart represent true circles and note that if you draw a line from the center of a circle to any point on its circumference, such a line will always meet the circumference at right angles. The important point is that the line of position, or Sumner line, which represents a short arc of the circle of equal altitudes, is always at right angles to the direction or azimuth of body observed.

FIX FROM TWO STARS.

From the single observation plotted on preceding chart, only a single line of position was obtained. This is not sufficient to fix position of ship. If, however, navigator observes two bodies at approximately the same time, two circles of equal altitude can be had. The ship must be on each circle and therefore can be only at one of the two points where the circles intersect. On the chart it is assumed that navigator has observed two stars, Alphard being in about the same position as the sun on previous chart, with Rigel almost on the boundary between Peru and Ecuador; and so two circles of equal altitude result. The ship is known to be near the northern intersection of the circles and two lines of position are crossed at that point for a fix.

The two charts thus discussed present the principles which underlie work of navigators at sea. However, it would be impossible to plot accurately on charts which represent almost half the world, even if these charts were as big as the projection now before you on the screen. For example, the radius

of the big circle is something like 3000 miles, and evidently you would have great difficulty in plotting 2998.5 miles with an accuracy of one-half mile, which accuracy is not unusual in routine chart work.

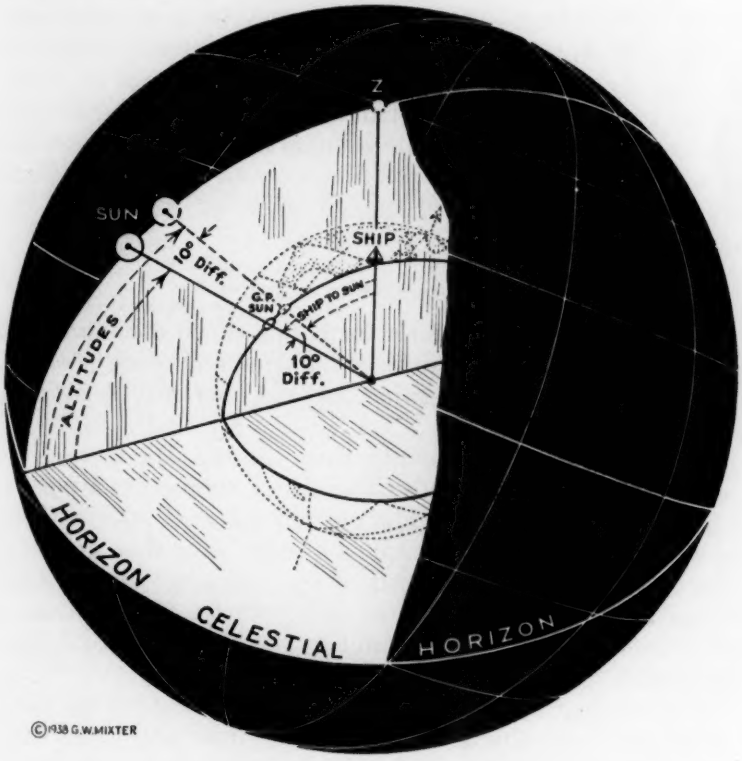


FIX FROM TWO STARS

ALTITUDE DIFFERENCES.

Here we have a perspective of a particular case of use of corrected altitudes. The observer is in about the position of Montauk Point; for purposes of this discussion, facts in the Almanac have been forgotten; and our sun is shown in two positions. Note that the *difference* between the two *altitudes* of the sun, 10°, is also *difference* in the *distances* from ship to the two geographical positions of sun. In the case of the lesser altitude, ship is 10° farther away from sun. When

altitude is 10° greater, ship is 10° or 600 miles nearer or toward sun. In the practice of navigation, presently shown, these differences may range from a few minutes of arc, or miles of distance, up to about 40 miles.



ALTITUDE DIFFERENCES

Altitude 1′ of arc LESS
Ship 1 mile further AWAY *from the Sun*

Altitude 1′ of arc GREATER
Ship 1 mile nearer or TOWARD *the Sun*

For this illustration, we have imagined the sun in two quite different positions, although in fact at the instant of an observation, the sun is in a single, definitely known position. Under such circumstances, the difference between two alti-

tudes of sun determines difference between the distances from G. P. sun of two observers at different places on the earth.

The fact that *difference* between *altitudes* measures *difference* between *distances* is the basis for laying down a Sumner line. This method of altitude differences was first developed by Marcq St. Hilaire of the French navy in about 1876 and now is the accepted method of the new navigation. When using this procedure, neither geographical position of body observed nor circle of equal altitudes need be plotted. Charts of large areas on a small scale such as now on the screen are not used; and the line of position may be plotted on large scale charts or plotting sheets, or even on a page of the navigator's work book.

PLOTTING A LINE OF POSITION.

Accepted general methods for laying down a Sumner line assume a *trial* position at or near the dead reckoning position, and then *correct* this position by the method of altitude differences.

Laying down a Sumner line from the sun, the moon, or a star, is illustrated by this drawing which represents a portion of a plotting sheet on which is plotted a line of position from the sun. Such work sheets are on a larger scale than are ocean charts and generally are used at sea, although the prudent navigator, from time to time, will transfer his position as found on the plotting sheets and mark it on the actual chart over which he is sailing.

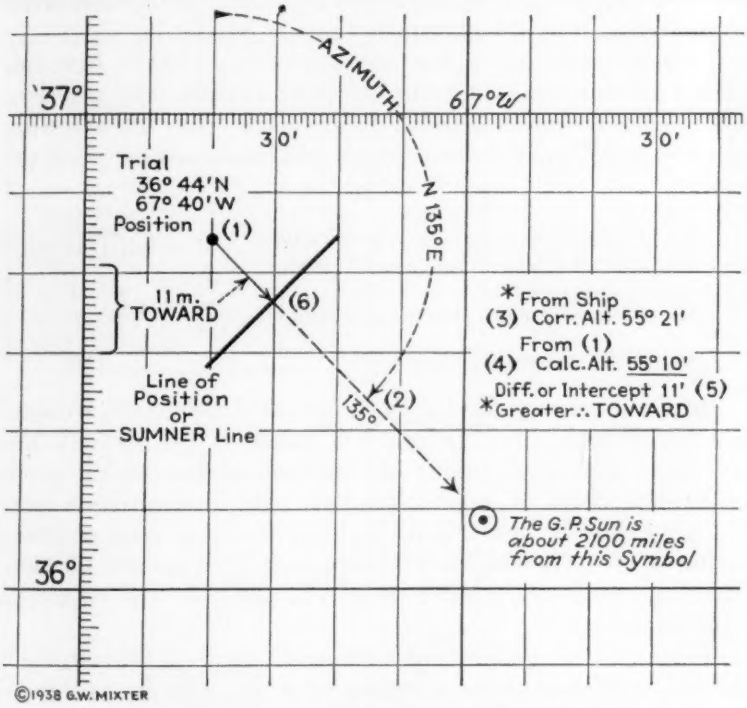
The navigator goes on deck. With his sextant he takes, for example, the altitude of sun's lower limb and notes exact time of his observation. Sextant altitude is then corrected to a true altitude as if observer were at center of earth. Position of sun is taken from Nautical Almanac for the date and instant of time of observation. Thus, two facts have been developed:

First: *Altitude from ship*, as corrected.
Second: *Position of sun*, as defined by latitude and longitude of its geographical position.

Navigator now selects an assumed or trial position such as that marked (1) on chart. He may choose to work from dead reckoning position or he may select some nearby point within not more than 40 miles from the D. R. in order to

facilitate use of certain tables. In either case, *the same Sumner line would result.* Whatever trial position he selected, its latitude and longitude are noted, which are, in the case of our example, 36° 44′ N. and 67° 40′ W.

The next step is to calculate an altitude as if taken from trial position at the time of the actual observation from ship. Data for this calculation are the already known latitude and



PLOTTING A LINE OF POSITION

longitude of geographical position of sun, as taken from the Almanac, and latitude and longitude of trial position. Whatever method be used, the calculated result is a true altitude as from center of earth and need not be corrected.

The calculation itself includes solving a spherical triangle by any one of many methods. In recent years, new methods and tables have been developed which greatly simplify the work of determining calculated altitudes. The latest of

these methods, entitled *Tables of Computed Altitude and Azimuth*, or known simply as H. O. No. 214, tabulates innumerable solutions, and is so arranged that calculated altitudes from a properly assumed trial position may be taken directly from tables with an addition of one simple correction.

The same page of these tables also gives the bearing or direction of observed body from trial position. This angle is known as the *azimuth* which presently will appear as essential for plotting a line of position by modern methods.

Thus we will assume, for purposes of this lecture, that calculated altitude and the azimuth, both as from trial position, have been determined without difficulty and that the following data now are available for plotting the Sumner line as on the screen:

(1) *Trial position* as marked on plotting sheet.
(2) *Azimuth* from trial position, 135° true.
(3) *Altitude from ship*, as corrected ..... 55° 21′
(4) *Altitude from trial position*, as calculated ..... 55° 10′
(5) And thus, *Altitude Difference* of ..... 11′

With the azimuth and with the altitude difference, we shall plot the Sumner line. From trial position (1), draw a line 135° true, which will point in direction of sun which is the center of a circle of equal altitudes. Because altitude from ship is 11′ *greater* than calculated altitude from trial position, we know that the ship is 11 miles nearer or *toward* the sun. Therefore, step off 11 miles from trial position toward sun to point marked (6).

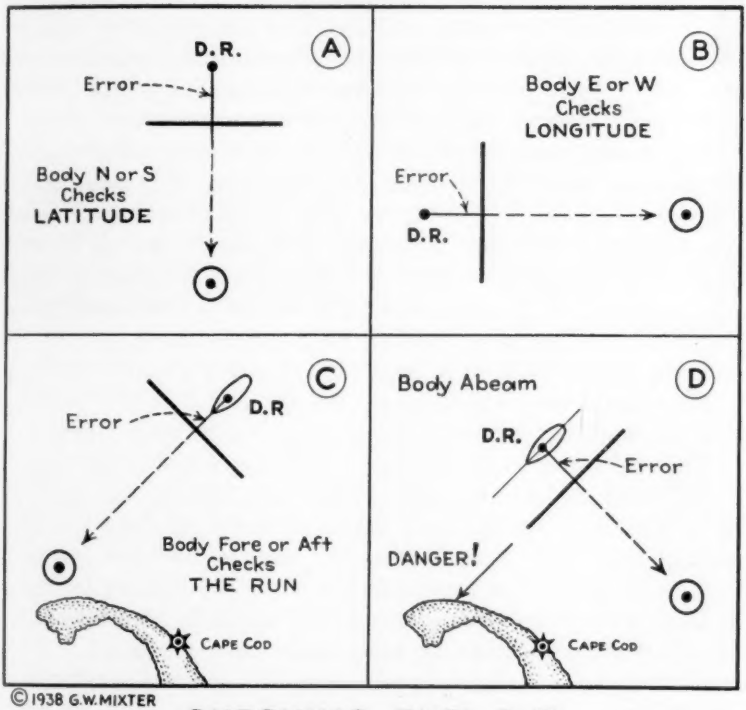
Through the point thus obtained, draw a line at right angles to the bearing or azimuth of sun. This is the line of position or Sumner line. The ship is somewhere along this line, but we do not know exactly where. Remember once more that a single observation gives only a line of position and does not give a fix.

Thus, by Marcq St. Hilaire's method of altitude differences, we have laid down a Sumner line. This line of position is, in fact, a short arc of a circle of equal altitudes but it has not been necessary to plot either the circle or the geographical position of the sun at its center.

CHECKING THE D. R.

Before concluding our discussion of Sumner lines, let us examine the value of Sumner lines under various conditions.

In Case (*A*), on the screen, the sun lies true south and the sketch represents the traditional noon sight for *latitude*. The same general result would be had by observing any body either north or south of the ship; for example, Polaris, which bears almost true north.



CHECKING THE D.R.

In Case (*B*), the sun is to the eastward and the resulting Sumner line checks the *longitude* which measures the east-west position of ship.

However, a line of position may be had from a body bearing in any direction and in Case (*C*) the sun, bearing ahead of a ship steering to clear Cape Cod, furnishes a position line which checks distance of ship from Cape.

Case (*D*) shows same ship with sun abeam. The old man thinks he is where ship is shown on chart on a course to clear the Cape. In fact, he is on the sun line, running parallel to his course and if the weather comes thick, the ship may pile up on Peaked Hill Bar.

Note too, that a Sumner line is like the line across the top of the capital letter T whose vertical leg then points toward the body observed. Evidently the value of a Sumner line in any given situation depends on the bearing or azimuth of the body.

The Outward Bound chart previously discussed does not show details of plotting various Sumner lines, but serves further to illustrate their use in practical navigation.

For example: navigator at (5), south of Montauk, wants a line to cross with the bearing of Montauk. The star Spica bears about S.W. or 230° true, and an observation of Spica gives the Spica line shown crossed with the Montauk line for a fix. At (7), an observation of sun to eastward checks longitude as about 72° W. A noon sight with sun true south gives the parallel of latitude running east and west on 40° 26′ N. somewhere on which ship must be. For the evening twilight fix, three stars were selected because the result would be more accurate than the intersection of any two Sumner lines.

Thus the navigator proceeds with his work from day to day, through night after night, always keeping his dead reckoning, which may be his only resource through days of thick weather, and until the moment the horizon and the sun or a star can be seen. He may take the stars at morning twilight, the sun in the forenoon, at noon and again in the afternoon, and at evening twilight he may again take the stars. How much work he actually does will depend upon requirements of his service, upon necessities of a particular situation, and upon the man himself.

Those of you here tonight who are without some technical training or knowledge of these matters probably find it difficult to understand and will find it more difficult to remember this rapid outline of principles and methods used to determine positions of ships at sea. If you go away satisfied that every Lighthouse in the Sky serves to guide the mariner over a so-

called trackless ocean, in much the same fashion as man-made lighthouses on land guide the coastwise pilot, then half the purpose of this lecture will have been accomplished.

Lastly and on the other hand, I do not want to leave with you any impression that the practice of navigation is a simple matter. We have not attempted tonight to discuss many details which make up the technique of the art. Each step is simple and easy, but there must be no blunders. Neither a dozen lectures nor all the books can make a navigator!

One must *practice* and *practice;* and learn to sense the import of every detail, and know when two and two make five.

Thus from practice, and books well taught and well learned, the observant Navigator, ever mindful of possible errors and disasters, learns to conduct his ship in safety to the haven where he would be.

Transformer With Wound-Core.—(*Electrical World*, Vol. 110, No. 1.) At the recent convention of the American Institute of Electrical Engineers a radically new form of core of simple structure and highly efficient performance was announced for the first time in a paper by E. D. Treanor of the General Electric Co. It is made by winding a long ribbon of magnetic steel in a tight spiral interlinking the copper coils of the transformer, a construction which has been designated as the " wound core." The new design eliminates or minimizes most of the objections inherent in prevailing core designs. The flux runs with the grain of the iron and all material in the core is active. There is but one gap in the magnetic circuit and it is short and of large area. Only one or two pieces of (cold rolled) strip steel are necessary to make the average small core. Waste in fabrication is small. Especially does the combination of a steel having high permeability and low losses in the high density range with a core structure which reduces the number and length of air gaps promise highly advantageous use of material, particularly in small transformers. Due to this ability to work the core at higher density, normal characteristics can be obtained with considerable economy of material and reduced over-all cost, despite the fact that the new steel is at present higher in cost than hot-rolled silicon steel in sheets. In recognition of the importance of improving regulation the copper loss of the wound-core transformers has been reduced and the core loss slightly increased. Meanwhile the exciting current is lower than with past transformers. They are lighter in weight. Credit is given to J. C. Granfield as the inventor of the wound-core construction. Designs for transformers with ratings of 1½, 3, and 5 kva. up to 7,620 volts have been placed in production.

R. H. O.

APPLICATION OF STATISTICAL METHODS TO MANUFACTURING PROBLEMS.*

BY

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ABSTRACT.

The application of statistical methods in mass production makes possible the most efficient use of raw materials and manufacturing processes, effects economies in production, and makes possible the highest economic standards of quality for the manufactured goods used by all of us. The story of the application, however, is of much broader interest. The economic control of quality of manufactured goods is perhaps the simplest type of scientific control. Recent studies in this field throw light on such broad questions as: How far can Man go in controlling his physical environment? How does this depend upon the human factor of intelligence and how upon the element of chance?

INTRODUCTION.

I sincerely appreciate the honor of the invitation to present to you this evening some of the recent developments in the application of statistical techniques in mass production.

What is there about the application of statistical methods in manufacturing of common interest to all of you? I assume that most of you are not statisticians looking for new worlds to conquer and therefore interested in the problems of production. Likewise I assume that many of you, at least, are not manufacturers looking for new tools with which to solve your problems. However, all of us are affected in one way or another by developments in the field of applied science. In fact the application of science is for the very purpose of satisfying the human wants of each and every one of us. Without such wants, there would be no applied science. Therefore each of us has an interest in industry's improvement of the technique of giving us what we want.

Furthermore the new statistical techniques developed and used by industry in the control of quality are of interest in

* Presented at a meeting held Thursday, February 28, 1937.

themselves as constituting extensions of scientific methodology that have now been tested and not found wanting—methods which make possible the most efficient use of raw materials, the reduction of the cost of production, and the maintenance of economic standards of quality.

The story of the application of statistical methods in manufacturing is, however, of much broader interest. All of us are interested directly or indirectly in the human control of some one or more of the physical aspects of the world in which we live. Now, the control of quality of manufactured product is perhaps the simplest type of control problem. Hence studies in this field may be expected to throw light on such broad questions as: How far can man go in controlling his physical environment? How does this depend upon the human factor of intelligence and how upon the element of chance?

The Problem of Quality Control.

Without more ado, let us sketch in broad outline the problem of making things to satisfy human wants. This problem is twofold: (*a*) discovery of what is wanted and of physical facts and principles, and (*b*) efficient use of the results of discovery. Engaged in determining what is wanted we have literally hundreds of consumer research agencies, trade associations, and the like, and engaged in determining ways and means of making use of physical facts and laws in producing things to satisfy such wants, we have more than 1600 industrial research laboratories in America alone. To sketch some of the potential advantages of the application of the recently developed statistical methods for research workers in all such work would constitute a story in itself. For lack of time we must pass it by tonight.

However, given the results of research, there remains the problem of using such results—the problem of development and design, then production, and last but not least inspection. Tonight we shall limit our consideration to mass production and consider primarily the three steps: specification, production, and inspection.

Now let us see what characterizes these three steps. What for example is a specification? In general, it is a technical description in words and engineering drawings of the thing that

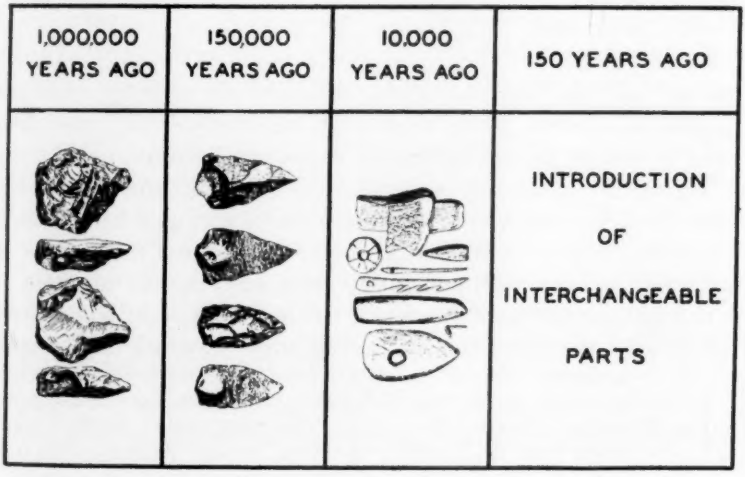
is wanted. The act of specification leads to a symbolic representation of a physical thing to be produced—a thing that exists as an idea in the mind of the engineer. Production on the other hand is an act leading to physical things, not symbols. Inspection as usually considered is the act of comparing the things produced with that symbolized by the specification.

We shall see how within the past twelve years fundamental changes have been brought about in the techniques underlying these three steps. We shall see that these changes are based upon fundamental changes in ideas as to the nature of the inspection process and as to what constitutes an adequate specification, what constitutes a standard of quality, and how much variation in the quality of things produced should from an economic viewpoint be left to chance. These changes in ideology, after all, are the most important elements in our story because ideas, concepts, and beliefs rule our actions.

SOME IMPORTANT HISTORICAL STAGES IN CONTROL OF QUALITY.

To give us a perspective from which to view recent developments, let us look at Fig. 1. That which to a large extent

FIG. 1.

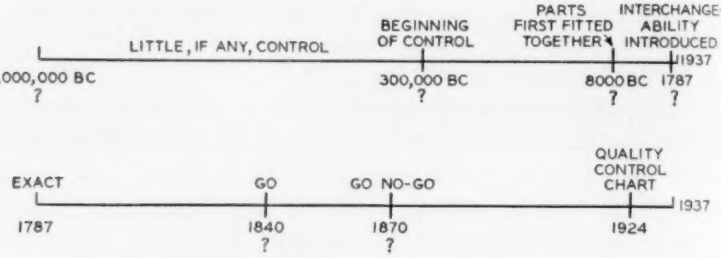


differentiates man from animals is his control of his surroundings and particularly his production and use of tools. Ap-

parently the human race began the fashioning and use of stone implements about a million years ago as is evidenced by the crude stone implements shown to the left of Fig. 1 which were recently (1921) discovered [1] just north of London. Little progress in control was made, however, until 10,000 years ago or thereabouts when man first began to fit parts together as evidenced by the holes in the instruments of that day illustrated in Fig. 1.

Throughout this long period apparently each man made his own tools, such as they were. As far back as 5000 years ago the Egyptians are supposed to have made and used interchangeable bows and arrows to a limited extent. It was not, however, until about 1787 or a hundred and fifty years ago

FIG. 2.



that we had the first real introduction of the concept of interchangeable parts. Only yesterday, as it were, did man first begin to study the technique of mass production!

From the viewpoint of ideology it is significant that at the time this first step was taken science was thought to be exact. Accordingly an attempt was made to produce pieceparts to exact dimensions. How strange such a procedure appears to us today, accustomed as we are to the concept of tolerances. But as shown schematically in Fig. 2, it was not until about

[1] This discovery is reported in "Man Rises to Parnassus" by Henry Fairfield Osborne, Princeton University Press, 1928. The photograph of the stone implements of a million years ago has been reproduced by permission from this most interesting book. The implements of 150,000 and 10,000 years ago as shown in Fig. 1 have been reproduced by permission from the fascinating story told in "Early Steps in Human Progress" by Harold J. Peake, J. B. Lippincott and Company, 1933.

1840 that the concept of a "go" tolerance was introduced and not until about 1870 that we find the "go no-go" tolerance.[2]

Why these three steps: exact, go, go no-go? The answer is quite simple. Manufacturers soon found that they could not make things exactly alike in respect to a given quality, it was not necessary that they be exactly alike, and it was too costly to try to make them exactly alike. Hence by about 1840 they had eased away from the requirement of exactness to the go tolerance. Still too much time was wasted unnecessarily in trying to stay reasonably close to the tolerance. Then came the idea of specifying the go no-go tolerance or the range within which the quality characteristic might vary and still be satisfactory. This was a big forward step because it gave the production man more freedom and brought a still greater reduction in cost. All he had to do was to stay within the tolerance range—he didn't have to waste time trying to be unnecessarily exact.

Though this step was of great importance something else remained to be done. The way the limits are necessarily set is such that every now and then pieces of product are produced with a quality characteristic falling outside the specified range —in other words, defective. To junk or modify such pieces adds to the cost of production. But to find the unknown or chance causes of defectives and try to remove them also costs money. Hence after the introduction of the go no-go tolerance there remained the problem of trying to reduce the fraction p of defectives to a point where the rate of increase in cost of control equals the rate of increase in the savings brought about through the decrease in the number of rejects.

For example, in the production of the apparatus going into the telephone plant, raw materials are gathered literally from the four corners of the earth. More than 110,000 different kinds of pieceparts are produced. At the various stages of production inspections are instituted to catch defective parts before they reach the place of final assembly and are thrown

[2] It will be noted that the first six dates shown in Fig. 2 are given with a question mark—authorities are not in unanimous agreement as to the exact dates. I think, however, that the dates here shown will be admitted by all to be approximately correct.

out. Here one faces the problem of finding the economic minima for the sizes of the piles of defects thus thrown out.

This problem of minimizing the per cent defective, however, was not the only one that remained to be solved. Tests for many quality characteristics—strength, chemical composition, blowing time of fuse, and so on—are destructive. Hence every piece of product cannot be tested for such a characteristic to see if it falls within the specified tolerances. Engineers must appeal to the use of a sample. But how large a sample should be taken in a given case in order to give adequate quality assurance?

The attempt to solve these two problems, giving rise to the introduction of the quality control chart technique in 1924, may therefore be taken as the starting point of the contributions of statistical technique to the control of quality of manufactured product in the sense here considered.

Why After 1900?

Why, you may ask, was it something like one hundred fifty years from the start of mass production of interchangeable parts to the time of the more or less intensive study of the application of statistical methods in this field? There are at least two important reasons.

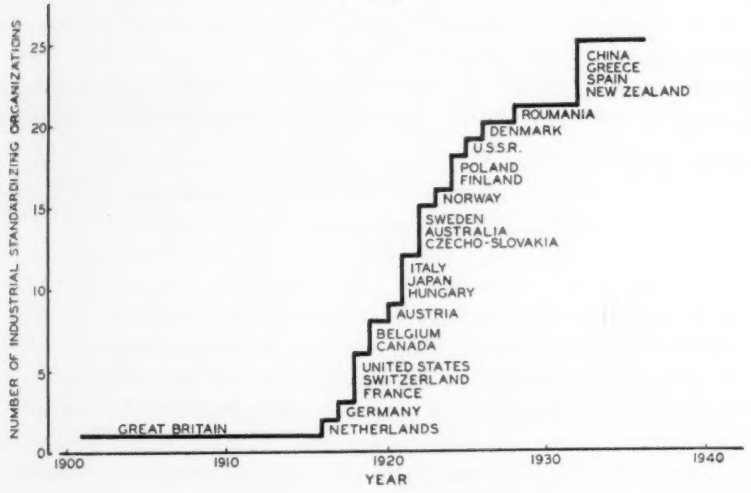
First, there was the rapid growth in standardization. Fig. 3 shows the rate of growth in the number of industrial standardization organizations both here and abroad. The first one was organized in Great Britain in 1901. Then beginning in 1917 we get a rapid spread of the realization of the importance of national and even international standards. Now, fundamentally the output of such standardization organizations is specifications of the aimed-at quality and in certain instances of methods of measuring this quality. But when one comes to write such a specification, he runs into the two problems discussed in the previous section—minimizing the number of rejections and minimizing the cost of inspection to give an adequate degree of quality assurance. Hence the growth in standardization spread the realization of the importance of such problems in industry.

Second, there was a more or less radical change in ideology. We passed from the concept of the exactness of science in 1787,

when interchangeability was introduced, to the concepts of probability and statistics which came into their own in almost every field of science after 1900. Whereas the concept of mass production of 1787 was born of an exact science, the concept underlying the quality control chart technique of 1924 was born of a probable science.

We may for simplicity think of a manufacturer trying to produce a piece of product with a quality characteristic falling within a given tolerance range as being analogous to shooting at a mark. Now, if one of us were shooting at a mark and

FIG. 3.



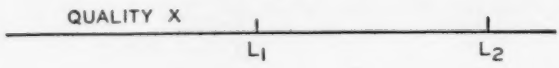
failed to hit the bull's-eye, and some one asked us why, we would likely give as our alibi, CHANCE. Had some one asked the same question of our earliest known ancestors, they might have attributed their lack of success to the dictates of fate or to the will of the gods. I am inclined to think that in many ways one of these alibis is just about as good as another. Perhaps we are not much wiser in blaming our failures on chance than our ancestors were in blaming theirs on fate or the gods. One element of human interest in our story tonight is that our William Tell, the manufacturer, has proved his unwillingness since 1900 to attribute all such failures to chance.

This represents a remarkable change in ideology which characterizes the developments in the application of statistics in the control of quality.

APPLICATION TO SPECIFICATION.

Step I in quality control, as we have defined it, is specification. Let us now consider the application of statistical methods to this step. With the introduction of the go no-go tolerances of 1870, it became more or less generally accepted practice to specify for any given quality characteristic X that this quality should lie within specified limits L_1 and L_2, represented schematically in Fig. 4. Such a specification is of the nature of an end requirement on the specified quality characteristic X of a finished piece of product. It provides a basis on which the quality of a given product may be gauged to determine whether or not it meets the specification. From

FIG. 4.



this viewpoint, the process of specification is simple indeed. Knowing the limits L_1 and L_2 within which it is desirable that a given quality characteristic X shall lie, all we need to do is to put these limits in writing as a requirement on the quality of a finished product. With such a specification at hand, it is presumed to be possible through measurement to classify a piece of product as conforming or non-conforming to specification.

As we have seen, however, two difficulties arise with this form of specification. Suppose that the quality in question, the blowing time of a fuse for example, is one that can be determined only by destructive tests. How can one give assurance that the quality of a given piece of product will meet the specification without first destroying it? Or again, if we concern ourselves with the fact that even where the quality characteristic may be measured, there is always a certain expected fraction p falling outside the tolerance limits, how can we go about attaining an economic minimum to this fraction non-

conforming? A little reflection shows that the simple specification of a go no-go tolerance is not satisfactory in such instances from the viewpoint of: (1) Economy, and (2) Quality Assurance.

At this juncture statistical theory steps in with the concept of two limits A and B which we shall term action limits, and which lie, in general, within L_1 and L_2. These limits are such that when the observed quality of a piece of product falls outside of them, even though it be still within the limits L_1 and L_2, it is desirable to look at the manufacturing process in order to discover and remove, if possible, a cause of variation which need not be left to chance. In other words, whereas limits L_1 and L_2 provide a means of gauging product already made, action limits A and B provide a means of directing action toward the process in order that the quality of product not yet made may be less variable on the average.

Furthermore, the statistical theory of quality control introduces the concept of another point C lying somewhere between the action limits A and B which is the expected or the aimed-at average quality in an economically controlled state. We should perhaps pause a moment to note the significance of the point C from the viewpoint of design or the use of material that has already been made. Let us take, for example, a very simple case of setting over-all tolerances. Suppose we start with the concept of the go no-go tolerance of 1870 and wish to fix the over-all tolerance for n pieceparts assembled in such a way that the resultant quality of the n parts is the arithmetic sum of the qualities of the parts. An extremely simple example would be the thickness of a pile of n washers. The older method of fixing such a tolerance is to take the sum of the tolerances on the pieceparts. This is generally many times too large from the viewpoint of economy. The efficient way of setting such tolerances is in terms of the concept of the expected value and the expected standard deviation about this value. In other words, the concept of expected value is of fundamental importance in all design work in which an attempt is made to fix over-all tolerances in terms of those of pieceparts.

Thus we see how, starting with the simple concept of a go no-go tolerance in a specification as illustrated in Fig. 4, it is

necessary in many cases [3] for economy and quality assurance reasons to introduce certain action limits A and B and also a certain expected value C to be used in design formulae. The situation corresponding to the simplest case is shown schematically in Fig. 5. Statistical theory alone is responsible for the introduction of the concept of action limits A and B and the expected value C.

The next question to be considered is that of determining the points A, B, and C. It is extremely important to note that whereas L_1 and L_2 can for the most part be set a priori, the other three points cannot be thus set because they depend upon the results economically attainable in the process of production and in the process of inspection. In particular, the action limits A and B call for action directed at the production process. Let us therefore consider next the second step in quality control, production.

FIG. 5.

APPLICATION TO PRODUCTION.

As already noted, if science were really exact and physical laws were such that an engineer could figure out beforehand just how to make exactly what he wanted, there would be no story to tell tonight. Though scientists in the past may at times have entertained this fair dream, such hopes have long ago been blasted. Seemingly we are foreordained to live in a world where chance or unknown causes play their part. Even in the simplest case where we try to do the same thing, or go through the same kind of operation, again and again under what appear to us to be the same essential conditions, our

[3] It should be noted, of course, that if there is no economic or quality assurance reason for going beyond the concept of the go no-go tolerance, statistical theory has nothing to add. Likewise, it should be noted that, although the action limits A and B may lie within the tolerance limits L_1 and L_2, product already produced and found within the limits L_1 and L_2 is still considered as conforming although outside A and B. In other words, the action limits A and B do not apply as a gauge for product already made.

results are marked by certain variations which we cannot explain in terms of known causes. The real economic problem in such a case is to have some kind of practical technique for determining when we have gone as far as it is economically feasible to go in finding and eliminating causes of variation.

Control Chart Technique—How it Works.

Now the control chart technique referred to in Fig. 2 is the practical contribution of statistical theory to this problem of indicating when one who is trying to do the same thing again and again should look for assignable causes. Let us think of any group of chance causes of variation as consisting of a subgroup that can be found and controlled and of a remainder which it is perhaps beyond the power of man to find and control. For the purpose of picturesqueness, let us think of these assignable or findable causes as little demons that one is trying to remove from the production process. The control chart technique may then be thought of as a trap to catch these demons. Let us see how it works.

I take as an example a problem that arose in the early testing out of this technique—the development of a high insulation material with minimum variability. Two hundred four different pieces were made and tested and gave the results shown in Table 1, where the numbers are in megohms. The

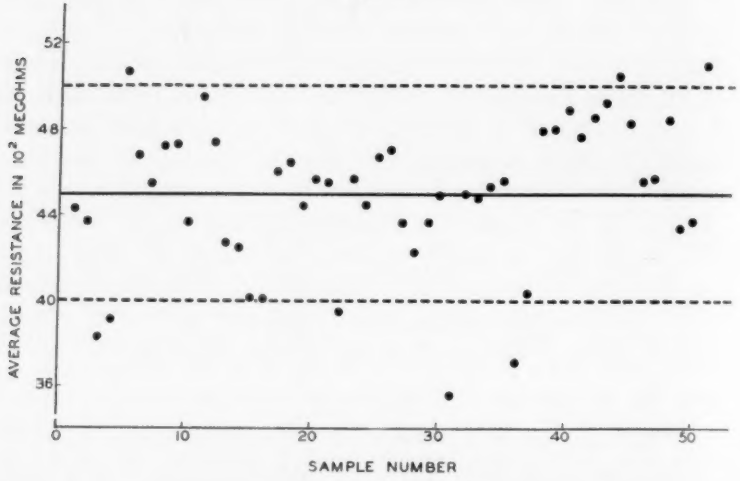
TABLE I.

5045	4635	4700	4650	4640	3940	4570	4560	4450	4500	5075	4500
4350	5100	4600	4170	4335	3700	4570	3075	4450	4770	4925	4850
4350	5450	4110	4255	5000	3650	4855	2965	4850	5150	5075	4930
3975	4635	4410	4170	4615	4445	4160	4080	4450	4850	4925	4700
4290	4720	4180	4375	4215	4000	4325	4080	3635	4700	5250	4890
4430	4810	4790	4175	4275	4845	4125	4425	3635	5000	4915	4625
4485	4565	4790	4550	4275	5000	4100	4300	3635	5000	5600	4425
4285	4410	4340	4450	5000	4560	4340	4430	3900	5000	5075	4135
3980	4065	4895	2855	4615	4700	4575	4840	4340	4700	4450	4190
3925	4565	5750	2920	4735	4310	3875	4840	4340	4500	4215	4080
3645	4190	4740	4375	4215	4310	4050	4310	3665	4840	4325	3690
3760	4725	5000	4375	4700	5000	4050	4185	3775	5075	4665	5050
3300	4640	4895	4355	4700	4575	4685	4570	5000	5000	4615	4625
3685	4640	4255	4090	4700	4700	4685	4700	4850	4770	4615	5150
3463	4895	4170	5000	4700	4430	4430	4440	4775	4570	4500	5250
5200	4790	3850	4335	4095	4850	4300	4850	4500	4925	4765	5000
5100	4845	4445	5000	4095	4850	4690	4125	4770	4775	4500	5000

data are given here in the order that the pieces were made, beginning at the top of the first column, reading down that column, then down the second column, and so on. The practical problem is simply this: Have all the little demons been removed from the production process? In other words, are the resultant variations such that economically they should be left to chance?

We cannot take time here to describe the details of the technique other than to say that it consists in this case of dividing the 204 observed values into fifty-one sets of four in the order in which they were taken, finding the average for

FIG. 6.



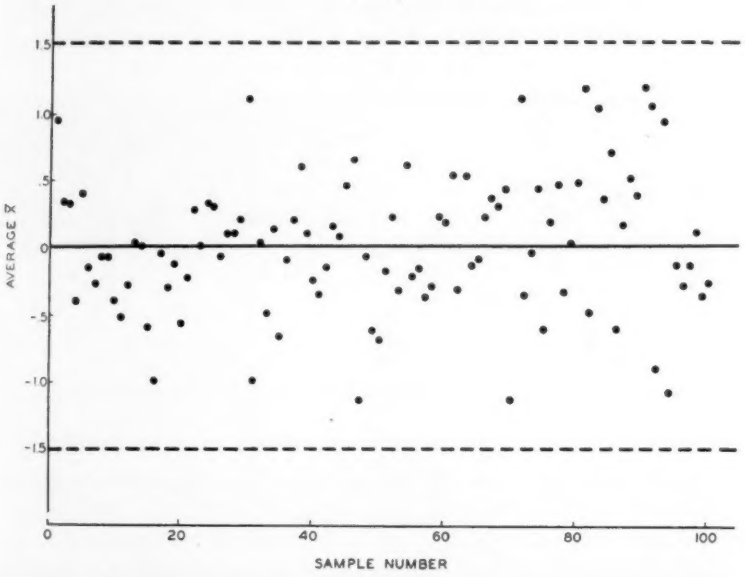
each set, and plotting these averages on a vertical scale as shown in Fig. 6. By going through a little computation, we get the two limits which are shown by the dotted lines in this figure. If any point falls outside these limits, the technique says to look for a little demon. The rest of the story in this case is simple indeed. They looked, they found, they removed some demons. As a result they succeeded in reducing to a minimum the variability which should be left to chance.

Years of experience in the application of such techniques have met with success. The technique itself is one which could be attained only through the use of statistical theory.

How the Technique Works in a Case Where There Is No Demon of Chance.

It is somewhat illuminating to see just how this test works in a case where I think all of you will agree that one has gone as far as he can in removing the causes of variation. Suppose I had a bowl of chips before me like the one I have in my hand and that we write numbers on these chips distributed, let us say, in the well-known bell-shaped normal distribution. Suppose one of you were to step up here and, after being blindfolded, you mixed the chips in the bowl and drew out one and we recorded the number here on the board. Suppose you put

FIG. 7.



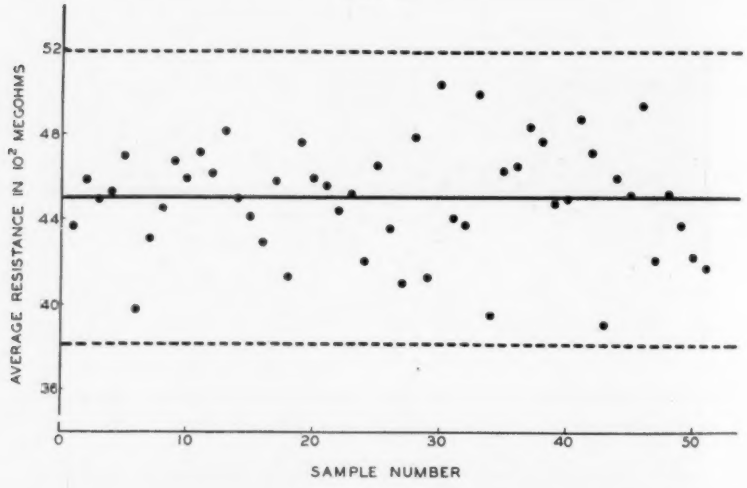
the chip back, stirred them up, and drew out another number, continuing this process until we had four hundred numbers on the board. Now, is there any way that any of you know in which you might under such circumstances control the numbers you draw, assuming, of course, that the chips are of the same size and feel the same? I take it that you would agree that the kind of variations you get in the numbers through such an operation is beyond your control. Well, let us see what the criterion shows when tried on such a set of four hundred numbers grouped into samples of four. Fig. 7 shows the

averages of such a series of samples—you would not have occasion to look for any little demon or findable cause. The chart technique would not lead you astray.

The Human Element in the Technique.

I said something in the introduction about trying to indicate the role of intelligence in the application of such techniques. It is perhaps trite to note that as the basis of any inference there is some hypothesis. There could be no facts without a theory and there could be no theory without a fact. Take, for example, the set of 204 observations shown in Table

FIG. 8.

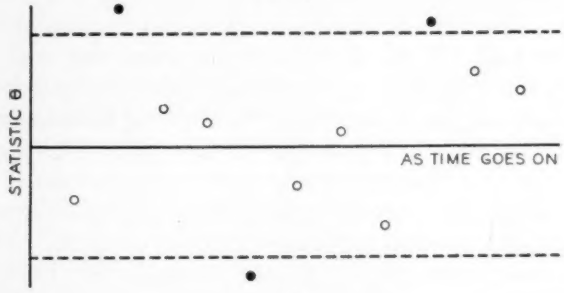


1. So far as the data are concerned, they are simply a set of 204 numbers. It is the way you use the numbers that counts. Note, for example, that we took the sets of four in the order in which the pieces were made. Suppose now that instead of doing this, we were to put the 204 numbers on a set of as many similar chips, put the chips in a bowl, and draw the numbers out, one at a time. Suppose then that we were to apply this same criterion, taking the first four, the second four, and the like, and plotting the averages of the sets, what would we get? One such experiment gave the results shown in Fig. 8; all the points are within the action limits. By mixing these

numbers one has lost some essential information that all the King's horses and all the King's men could not put back into the data.

There is in the literature on the application of such tests a very important statement, namely, that the one who takes the data must first divide them into what is termed rational subgroups.[4] I do not care to worry you about the technical meaning of this term except to point out that before you can successfully apply a test to catch one of these little demons of chance, you have to use your head in this process of dividing the data into rational subgroups. In other words, human intelligence, the ability to make hypotheses, is still the greatest power given to man in the control of his surroundings, even in

FIG. 9.



this simple case. But given intelligence to make hypotheses, there is something that statistical theory contributes through the control chart technique that is essential to the job of going to the economic limit in eliminating causes of variation and thereby getting control of a process to the limiting extent to which one can hope to go.

That is to say, given a situation in which you have an intelligent grouping of the data, statistical theory contributes a definite operational technique whereby you can calculate a statistic θ such as an average, fraction defective, or the like, which when plotted in a control chart schematically represented in Fig. 9 tells one when to look for trouble. When a point falls outside, look for trouble in the process; when it falls

[4] See, for example, Shewhart, W. A., "Economic Control of Quality of Manufactured Product," D. Van Nostrand and Company, New York, 1931.

inside, assume that ALL'S WELL. The dotted lines are the practical action limits A and B discussed under Step I—specification.

APPLICATION TO INSPECTION.

Some Early Perplexing Problems.

Production is followed by inspection, Step III in the control process; someone must look upon that produced and say whether or not its quality is what it was supposed to be. In principle a manufacturer first specifies, then produces, and then inspects. Classic practice is to assign these jobs to three separate departments or at least to different personnel. Ever since there was production there has been inspection; so let us look at the fundamental inspection problem.

The production department turns out a lot of N pieceparts or units. Two conditions may arise: (*a*) it may be too expensive to look at all N units even when the test is non-destructive, (*b*) the test may be destructive, as tests for chemical composition, breaking strength, blowing time of fuse, etc., and we have no other practical choice than to appeal to a sample. In fact this problem constitutes the door wherein statistics made its entry into the field of manufacturing in the sense of quality control as considered here tonight. The intricacies of this problem are legion, but we do not have to consider this mountain of detail to see clearly a fundamental contribution of the statistical theory of quality control.

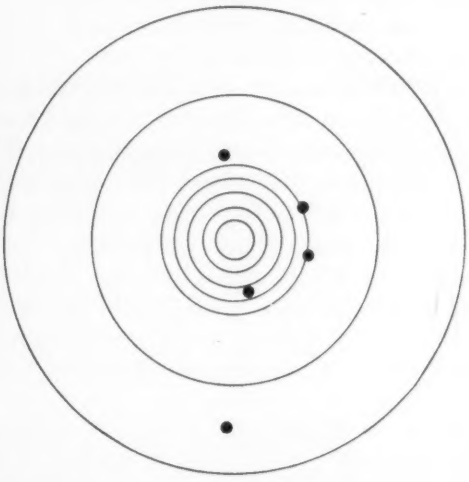
I take it that all of you have either shot at a mark or watched someone else doing so. Hence I shall start with a question to which some or all of you may be willing to risk an answer. Fig. 10 shows the placement of five shots fired by the same person at the bull's-eye. The question I want to raise is: Where will the next shot fall if fired in the same way by the same person? To make the question a little more obviously similar to the inspection problem, I might ask: Suppose the person is to fire a series of N shots of which the first five are shown in Fig. 10. What fraction p of these $N-5$ shots will fall within a specified circle?

Possibly some of you at least will be cautious and say that you wouldn't attempt a prediction on such meagre information. But suppose that instead of shots we have 25 fuses and the

blowing times for five of them. We may think of the chance cause system in the production process as producing variation in the blowing times. Having seen by test where the chance causes place the blowing times of the five, what can you say about the blowing times of the twenty as yet untested?

In respect to the question about the five shots, you may suggest that you ought to take a few more before risking an answer. However, in the case of the fuses, you will pretty likely think of your pocketbook before you answer. Possibly you now begin to feel, even if you have not previously done so, the way in which economics enters such questions.

FIG. 10.



But let us not worry over these two comparisons too much. Let us take at its face value the suggestion that we need more than a sample of five. Let us think back to the eve of November 3, 1936. One of the questions of the day was whether or not the published results of the Literary Digest poll of more than a million was sufficient to tell the story of the morrow. It was not. Size alone is not enough. This is one of the important facts which an inspection engineer learns early in the game.

There are lots of other knotty situations for the inspection engineer to face. For example, let us refer again to the place-

ment of shots in Fig. 10. You will note that three of the shots are to the right of a perpendicular to the base of this figure drawn through the bull's-eye. Suppose this were your target, would you pull a little to the left the next time you shot? That is to say, would you infer from the placement of the five shots, even though you had no other evidence, that there were some constant or assignable causes—some little demons—tending to place your shots to the right of this perpendicular? Everyone to whom I have put this question has answered yes. They have said that they would aim a little to the left to "correct" for this apparent effect.

Well, now I will let you in on a little secret as to how the shots on that target were fired. We started with a bowl of 1000 chips on which numbers were marked in such a way that there was a normal distribution in the bowl; a chip was drawn by one of us blindfolded, the number recorded, the chip returned to the bowl, and this number was taken as the X displacement of a shot; the Y displacement was obtained in a similar way by another drawing. With this information at hand, I think you will agree that your tendency to pull to the left in this case would not have been justified. In fact, such an effort to "correct" would tend to increase the spread of your shots on the target beyond what would in such a case be necessary. In other words, if we followed such a procedure in this particular case, we could not reduce the variability to a minimum.

To discuss the separate aspects of this problem is enough for an evening in itself. All I wish to do here, however, is to get all of us to feel some of the uncertainties in the interpretation of a sample. In so doing I will have gotten you to sense some of the stumbling blocks that lay in the path of early attempts to develop a rational theory for inspection engineering. In other words, you get a little of the atmosphere existing at the beginning of the application of statistical theory and technique to inspection in the sense considered in this paper.

Let us get back to the fact that some of you may have felt that the sample of five shots was too small to tell you much about where the next ones would fall and the fact that some of you may have wondered why a sample of more than a million failed to indicate the landslide of November 3, 1936.

Of course, one could find lots of advice to the effect that statistical sampling theory applied only to certain kinds of samples such as random and representative ones. But how is an inspection engineer to know a random or representative sample when he meets one face to face? That was the rub! The inspection engineer had to answer that one before he could taken on another.

This was one side of the story. The other was that it was a pretty well established fact that conditions exist in certain realms of nature where experience had justified predictions made on the basis of probability theory. Witness, for example, the insurance business, many molecular phenomena, the throws of a symmetrical die, drawings from a bowl of similar chips, or the distribution of suits in a well-shuffled deck of cards.

What Was Done.—Here then was the setting. What was done? Well, it was to try to take account of what we know about a sample in addition to its complexion and size. For example, as soon as I told you how the sample of five shots, Fig. 10, were made, you probably agreed that such variations are the kind that we must leave to chance in conducting such a drawing. Let us then just get a wee picture of the importance of what we know about the origin of a sample as a factor influencing our ability to predict.

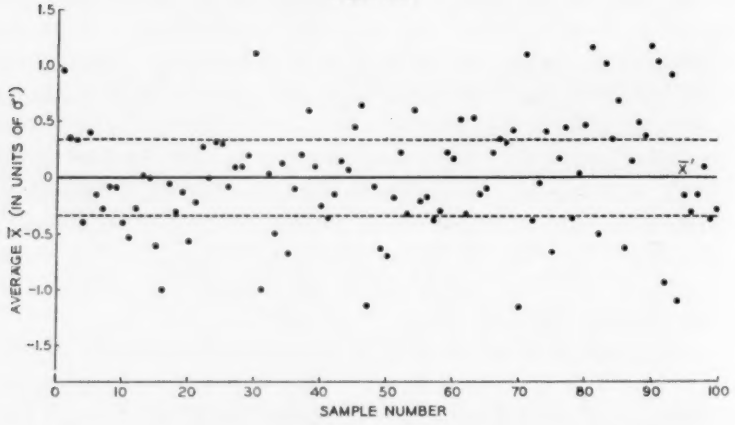
I have here a bowl containing 1000 chips physically similar to the one I hold in my hand. On each chip is a number. The distribution of numbers is in accord with the normal law. The arithmetic mean of these numbers is zero and the root mean square deviation is 1. With this information, I can make a lot of verifiable predictions about samples of any size n drawn with replacement from this bowl, without first drawing a sample.

For example one can say that in, let us say, N drawings of samples of size n, approximately 50 per cent of the averages of these samples will fall within the limits $0 \pm \frac{.6745}{\sqrt{n}}$. Fig. 11 shows the results for one such experiment of 100 samples of four. It worked pretty well. The number of averages within is 52 per cent as compared to an expected 50 per cent. This

condition of predictability exhibited by the bowl represents an ideal. If in some way one could come to know a process of production well enough that he could predict the quality of future output of that process with as much justified assurance as he can predict the results of future drawings from the bowl of chips here on the table, he would have gone as far as one may reasonably hope to go.

Now, let us assume that we don't know the average and standard deviation even though we know that the distribution of numbers has the same normal shape. Have we any way of drawing the limits such as shown in Fig. 11 that will include 50 per cent of the averages? The answer is No. First

FIG. 11.

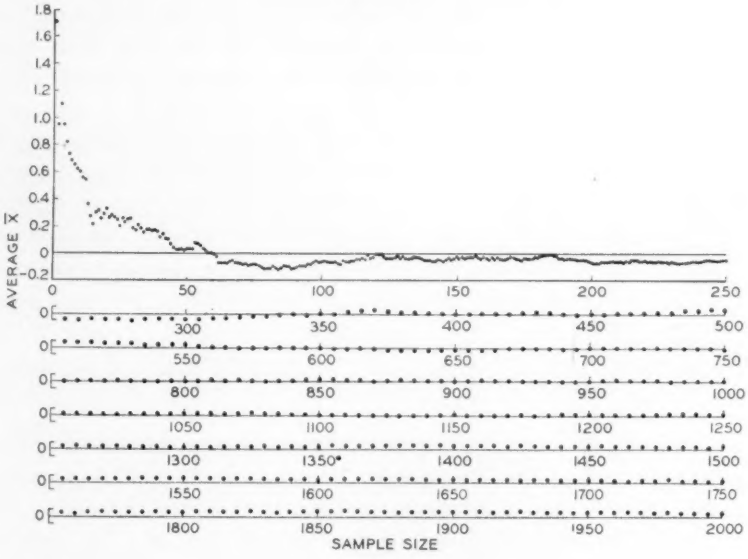


we must find the average and standard deviation. Suppose you can find these only by sampling. This corresponds to the practical case, where instead of drawing from a bowl we have the fluctuations in some quality characteristic of pieces of a given kind of product produced by a given kind of process.

How large a sample would you have to take from the bowl before you could predict as well as in the case above about the 50 per cent range for future samples of four? So that you may have some basis for risking an answer, assuming that you are not already professional statisticians, let us see how rapidly and in what sense the average of a sample of n approaches the true average in this bowl. Fig. 12 shows one such experi-

mental determination. The ordinate of a point is the observed average for the sample of size corresponding to the abscissa of that point. Of course, if you took another series of 2000 drawings and plotted the points for the same set of sample sizes the set of points would almost certainly not be the same. In fact they might start any place from + 3 to − 3 (these being the maximum and minimum numbers in the bowl) but in general the points would tend to hug the zero line progressively closer with increase in sample size much as shown in this figure.

FIG. 12.



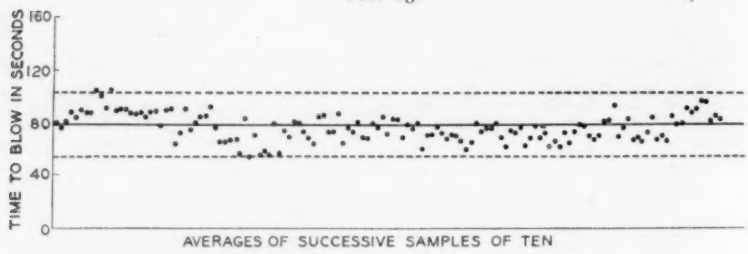
The first point I wish to make is that the rate of approach is slow. I don't believe you would think much in general of prediction from samples of 25 or even 50. This is particularly true when you learn that the rate of approach of an observed standard deviation is much slower, and you need that too in order to set the limits. In fact, you might want to go to a sample of 500 or 1000 before you would be satisfied with the likely reduction in your error of prediction.

Now, the second and even more important point I wish to make is that there is no royal road to derive such limits from a

sample so as to reduce the required sample size. Be he king or peasant every man must travel this same road.

But this is not the crux of the practical case. Here we have assumed sampling from a bowl. In practice we must first convince ourselves that a sample behaves as though it were drawn from a bowl. How can an engineer do this? The answer given by the theory and practice of the use of the control chart shows that we must first get rid of assignable causes revealed by such a method. In other words, in order to attain desirable predictability in the probability sense, we must first apply the quality control chart technique to give assurance that the causes of variability are such as must from a practical viewpoint be left to chance. In general, to do this requires quite a large sample as I have shown in detail elsewhere.

FIG. 13.



All I can do here is to show you a sample of the proof of the pudding. Fig. 13 shows certain practical limits for the quality of 99 per cent of the product of a certain kind of fuse in respect to the blowing time (a destructive test). The points are averages of 10. They stay within almost as well as the data from a bowl!

Practical Significance.

What has statistical theory and method contributed to the third step in control, inspection? Well, first, it has shown that in the interpretation of the sample we need to go behind the sample. We need to know how it was taken and most certainly we need to consider the available evidence as to whether or not the sample came from a controlled process. That is, we are thrown back on the evidence as to the degree of economic control obtained in the second step, production. It has shown very definitely that in order to minimize the cost

of inspection requisite for giving a specified degree of quality assurance, it is necessary first to attain a state of statistical control as evidenced by the satisfaction of certain quality control chart criteria.

This has made necessary two new techniques in the field of inspection.

(*a*) *Quality Report.*—A continuing quality report providing a record of the evidence of the state of control of the quality.

(*b*) *Inspection Practices.*—The preparation and use of inspection practices that take into account the state of control of the quality.

The quality report not only furnishes a background upon which to interpret the observed quality in a current sample of product but the central line in the chart approaches as a statistical limit the expected value C to be used in the specification of currently economic standard quality. It should be recalled that this C is the expected quality that enters into the computation of the overall quality of a design in terms of the qualities of the parts and is therefore a necessary factor. A third use of the quality report is to provide for design and production engineers evidence of lack of control or the presence of assignable causes of variability which should not be left to chance.

Now we are in a place to consider a very important potential contribution of mass production to scientific industrial progress. You have seen how in order to remove the assignable causes of variability in quality of product, it is possible to apply the quality control technique and you have seen how essential it is to have a high degree of control in order to give the highest quality assurance. But you have also seen that this potential state of economic control can only be approached slowly as a statistical limit. Control of this kind cannot be reached in a day. It cannot be reached in the production of a product in which only a few pieces are manufactured. It can, however, be approached scientifically in a continuing mass production.

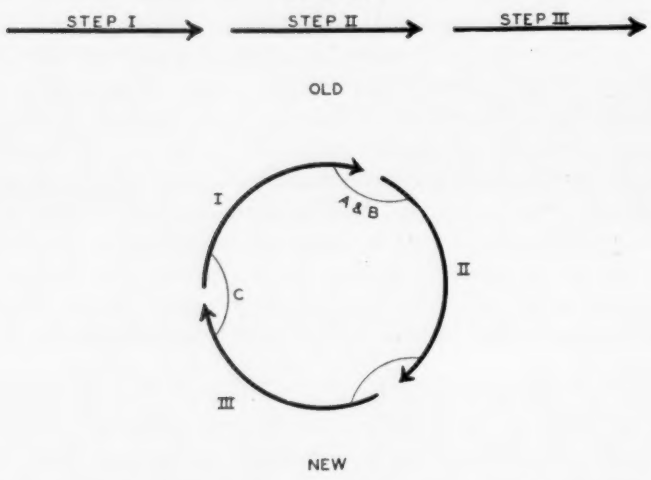
CONCLUSION.

We have seen clearly that statistical theory and technique has contributed something very definite to each of the three

steps in control. But it has done something much more than this. It has changed our whole concept of control.

As previously conceived, Steps I, II, and III were more or less independent. Of course, if we had *certain* knowledge they might be independent, but in science we can only have *probable* knowledge. What then has happened to our concept of three independent steps? The answer is shown schematically in Fig. 14. We see that the steps must go in a circle. They are no longer conceived of as being independent; they are *correlated*. We have seen that in order to take Step I we need action limits *A* and *B*. These must come from Step II.

FIG. 14.



Also we need the aimed-at value *C* to be used in design formulae but this must come from Step III. However, we cannot take the third step and attain the expected value *C* unless we first attain a state of statistical control, Step II, such that *C* is reached as a statistical limit. Finally we should note that both statistical theory and practice show that this state of control can be attained as a statistical limit only in the continuing process of mass production.

Thus you see how statistical theory has helped the William Tell of our story, the manufacturer, to hit his mark—the highest standard of quality and the greatest quality assurance at a given cost.

LARGE MOLECULES IN SYNTHETIC ORGANIC CHEMISTRY.*

BY

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INTRODUCTION.

It is a deep satisfaction to those interested in chemistry to realize the position of importance this branch of science has achieved, not only in its own right, but as a collaborator with other sciences, as a builder of industry and, indeed, as a benefactor to the general public in providing much that adds to the safety and comfort of living. To those whose principal interest lies in other fields, it may seem that the progress of chemistry has been uninterrupted and continuous. To those, however, who have been intimately associated in its progress, it is well known that advances are made by stops and starts, as some new tool becomes available, as some new concept suggests new methods of attack, or as progress in a related field opens the door to a new principle of investigation.

The history of chemistry consists principally of movement upon movement, each based on a new motivating force, permitting substantial progress, where previously no means existed to solve the apparently insuperable experimental or theoretical difficulties. We think of modern chemistry as originating with Lavoisier's application of the chemical balance to experimental technique. Mendeleef's conception of the atomic system has been the basis of countless investigations which are continuing even today in the study of isotopes and the transmutation of elements. Classical organic chemistry has grown around the idea of the quadrivalent carbon atom and more recently it is receiving a renewed stimulus from the study of materials composed of molecules of enormous size which are being found to constitute certain of the most important classes of matter.

* Presented at a meeting held Thursday, March 10, 1938.

These substances are becoming rather well known collectively under the popular designation of large molecules and by that is meant exactly what one would expect. Large molecules are ones composed of several hundred atoms or more, with known extremes running up to the general range of fifty thousand atoms. In terms of molecular weight this means molecular weights ranging from several thousand up to several hundred thousand. This is an entirely different order of magnitude of molecular size than is met with in heretofore well known organic chemical materials. There are several hundred thousand known organic chemical substances, but for the most part these have molecular weights below 400. For instance, quinine, the well known drug, has a molecular weight of 324 and contains forty-eight atoms, yet in this case alone some ten years of investigation were required to clarify its exact structure.

I recall in my early courses in chemistry that I was very much delighted with the opportunity of taking up a subject that promised to tell about the composition and behavior of the things that surround us. The elementary course told us of the elements and their simple compounds and that was fine. The organic courses told us of the alcohols and the acids and many interesting compounds, but mostly they were strange and new products and not the rather common things of our surroundings. Even the graduate courses were strangely silent on those materials, generally classed as organic, but not further clarified. Then it began to become apparent that a large number of the commonest things in our existence are in a general class by themselves and are not fully explained by the older chemistry. These include wood, cotton, wool, silk, leather, rubber, glue, our foods and even ourselves.

These substances, the new study of large molecules is attempting to explain and the importance of a further knowledge of their composition and behavior, has enlisted the attention not only of the organic chemists but of the physicists and biologists. For their proper investigation new techniques are required which are slow in their perfection. From a theoretical side there is danger of becoming lost in the atomic maze of their enormously complex structure. The attack on these problems has been particularly active in the last few years,

and important progress is being made. Already we are in possession of much valuable information on these substances which is being applied to good advantage in science, medicine and industry.

TECHNICAL DISCUSSION.

In my opinion the problem of comprehending the structure and behavior of these large molecular substances is the most difficult and baffling one which chemists have ever undertaken. The older tools of the organic chemistry are mostly worthless in such experimentation. These materials, in general, do not crystallize nor do they distill, thus eliminating the two best methods of purification. In general their solubilities are limited and even when proper solvents do exist, the standard freezing point depression and boiling point elevations are practically meaningless, due to the enormous molecular weights. Such progress as has been made has resulted from the origination of new experimental methods involving fractional precipitations, dialysis, ultra-centrifuging, and viscosity measurements. As yet, no outstanding single device for gaining needed information has been conceived, such as the chemical balance was in reference to the early problems of chemistry. Perhaps one is now in the making, but even if not the present technique can be relied upon for much progress even though laborious and slow.

On the side of theory the situation is somewhat better, as the basis of the structure of these new compounds is now fairly well understood. Such large molecular substances as have been studied seem to fall into two general classes, which may be called respectively polymers and condensation products. Polymers, as used in this connection, may be thought of as the reaction product of X identical or similar chemical units of moderate molecular weight which have reacted with each other to give a single molecular aggregate X times as great as the original chemical unit. Thus rubber is known to be a polymer of the unsaturated hydrocarbon, isoprene, which has the gross formula C_5H_8. It consists of nothing else, but has a molecular weight which indicates that several hundred isoprene molecules must have joined together to form one rubber molecule. To a certain extent this process can be reversed in

the case of rubber by heating, yielding mono-molecular isoprene. Similarly cellulose can be depolymerized by digesting with mineral acids, giving nothing but glucose, thus showing that it is a polymer of glucose, or more properly of anhydro glucose, since water is added in the hydrolysis procedure. The reverse polymerization of glucose, however, has never, as yet, been successful.

The other type of large molecules is called a condensation molecule. Such a molecule may be regarded as an indefinitely great reaction product of two organic compounds of moderate molecular weight which react in such a manner that the reaction product is capable of reacting further with the original reagents indefinitely. These condensation molecules are quite common as natural products. For example shellac, the exudation of an insect found in India, is known to be the condensation product of a very large number of molecules of rather complex organic acids and higher alcohols. It is believed that some or all of the proteins are also of this nature, and that condensation proceeds by the indefinitely continued reaction of the acidic and basic radicals of amino acids to give molecules of great size.

These theoretical conceptions are of particular help in understanding the nature of large molecular substances. They explain first how it is possible to go from ordinary organic chemical molecules to giant molecules at one step without finding materials of intermediate structure. The fact is that such is the case and until properly explained this added greatly to the mystery of these substances. Also it explains why the large molecular substances do not in general show the properties of a pure substance, such as crystalline structure. These polymerization and condensation reactions, while they do jump at once to high molecular weights, do not always stop at exactly the same values. Consequently the total end product is a mixture of similar, but not identical large molecules and thus differs from a chemically pure substance, where all of the molecules must be identical.

In view of the large size of these molecules, the arrangement in space of their units of construction is of particular importance. Obviously there are two principal patterns of construction in a large aggregate composed of like or similar units.

One of these is an end to end arrangement and there is good reason to believe that many large molecular substances are thus constructed. In these substances the long thread-like aggregates are held to each other only by physical forces of attraction and on heating these forces are lessened, permitting the substances to soften. Such materials show the property of being thermoplastic, as they soften with heat and harden again on cooling.

The other possible pattern is that of a more or less spherical aggregate, where chemical bonds hold the units of construction in all planes, giving a cross-linked structure. Several other large molecular substances are believed to have this type of construction and they differ markedly from the thermoplastic substances in being almost entirely resistant to heat up to their thermal decomposition point. Such materials show the property of being thermosetting. As an example of the thermoplastic resin we have pure gum rubber which softens easily with heat and becomes brittle with cold. Pure gum rubber, however, is easily reacted chemically with sulphur which establishes cross-linking between the thread-like large molecules and gives a new type of material that is much less affected by heat. This is the vulcanization process, explained in the terms of the new large molecule chemistry.

I hope that in this attempt to make a brief general summary of the known principles of our admittedly incomplete knowledge of large molecules, I have not caused more confusion than clarification. Perhaps it would be just as well to say, aside from any theory, that certain practical knowledge of certain large molecular substances is available and is being used industrially in advance of complete theoretical explanation. Of course it would be highly desirable to have all of the facts before going ahead with large scale industrial operations on an empirical basis. Without complete knowledge, of necessity, blunders will be made, products other than the best possible will be turned out and the manufacturer will be subjected to risk of rapid obsolesence of his investment due to new discoveries. However, in the practical world things are seldom done on an ideal basis and where incomplete knowledge serves a useful purpose it is invariably used. This puts a premium on securing additional useful information and such

research, supported by industrial profits, has in many previous instances added greatly to our store of scientific knowledge.

The particular branch of industry which has found a valuable asset in our existing knowledge of large molecules is that which is now generally called plastics. As many of you know, a plastic material is one that can be brought to a sufficiently soft condition, usually by heating, so that any desired shape may be imposed upon it by mechanical pressure. Then it may be hardened either by cooling or by a chemical reaction taking place within the material, so that it will retain the shape thus imposed upon it. There is nothing new in this principle which has been used since the early days of prehistory in the production of pottery, glass and many common articles. The important novelty that does exist in our rising plastics industry lies in the physical characteristics of the articles after they have been shaped. Experience has shown that certain newly discovered synthetic products produce articles of much greater utility and beauty than any previously known. Thus a definite reason has come into existence for gaining still more information in this new field of science.

SYNTHETIC LARGE MOLECULES.

Although significant research is being done on these large molecular substances in many fields, the most active investigation with which I am familiar is being done on synthetic materials for industrial use as plastics. This is an interesting reversal of an old tradition among organic chemists. From the earliest days of organic chemical research, the standard technique has been to isolate a crystalline substance or a distillable liquid, in order to get a pure substance which could then be identified and described. When a reaction resulted in a resin or pitch which could not be purified by crystallization or distillation, that research problem stopped right there. However, between the time of Hyatt's work on Celluloid around 1870 and Baekland's work on phenol formaldehyde resins in the early years of this century the idea gradually took form that chemical products might be of value for mechanical uses without being chemically pure. Furthermore, in view of the poor mechanical properties of liquids and crystals, resinous materials seemed best suited for such purposes, provided they

could have the right properties tailored into them and the wrong ones eliminated. This conception of predetermining useful mechanical properties of solid materials by appropriate control of chemical composition was a very new idea and since no materials other than the little understood, large molecular substances were suited to such uses, the difficulties were much increased. This is not the kind of a problem that the typical inventor can work out over the kitchen stove or in his garret. For more than a hundred years each generation of chemists has done what was possible with the experimental facilities and theoretical knowledge available. Yet it has been only within recent years that a dependable scientific basis has been laid for such work and surely the major accomplishments are still to come.

Since large molecular substances occur abundantly in nature and certain of them have naturally mechanical properties that make them useful for certain purposes, it was obvious that the first efforts to make synthetic plastic products should consist in the modification of natural ones. Dr. Goodyear's discovery of the vulcanization of rubber in 1839 was the first important discovery of this type. This work actually was carried out on the kitchen stove and Dr. Goodyear was a physician, not a research chemist. Nevertheless it was a most inspired and brilliant contribution which has had the broadest industrial significance. Two types of plastic material have come from this discovery, the soft, extensible rubber, such as is used in automobile tires and the less common hard rubber or ebonite which resembles somewhat the other solid plastics now used for molded articles. At about the same time Schönbein in Germany discovered that cellulose in the form of cotton could be nitrated, although it was not until 1865 that Hyatt discovered that cellulose nitrate plasticized with camphor could be fabricated into solid articles as the material which has since become well known under the trade name, "Celluloid." Just at the turn of the century it was discovered that casein, separated from milk, could be reacted with formaldehyde to yield another plastic material with valuable properties, particularly in its light color and freedom from fire hazard.

Judged by present commercial standards none of these modified natural materials, excepting the extensible vulcan-

ized rubber, is particularly well suited to the uses to which it has been put; that is to say a great many defects have been found in their performance as compared with an ideal material. A study of these defects is very illuminating, as indicating the specifications which a synthetic material would have to meet to surpass the modified natural products—mechanical specifications to be met by predetermined chemical composition. Celluloid is highly combustible, almost explosive, limiting the methods of processing, as well as adding a distinct hazard to its manufacture, storage and use. It is discolored by exposure to light and is too easily affected by acids, alkalies and organic solvents. Hard rubber turns to a dirty green color in the sunlight, as our telephone receivers used to do; it has an unpleasant odor and absorbs oils and greases. Physically it is rather brittle and must be used in thick sections for requisite strength. Casein, while the most attractive of the three in appearance, is badly affected by moisture and is so lacking in true plastic flow that most shapes must be machined, making it high in cost.

I do not wish to give the impression that the technical objections just cited are such as to bar these materials from all commercial applications. There is a well recognized principle in industry that old products never die. That is to say, a product which has once shown sufficient merit to command a market usually continues to hold at least a part of this market, even though superseded by a product which is technically superior. Particularly in a rapidly growing field such as plastics, the superior product may take all or nearly all of the new growth, leaving a progressively smaller percentage of the whole to the older product.

As the first of the modern synthetic plastics, the phenol formaldehyde resins, of which Bakelite is a well known example were brought out some thirty years ago. These resins, of which there are many modifications, are of the condensation type. Formaldehyde reacts with phenol, splitting out a molecule of water and this reaction product continues to react with elimination of more water until a mass consisting of large cross-linked molecules has been built up which has the desired characteristics of heat resistance, mechanical strength, and insolubility in all solvents. An important characteristic is that the reaction can be stopped while the material can still

be softened by heat. This intermediate material can then be ground to a powder and molded to any desired shape. In the molding process heat and pressure are applied which converts the powder first to a viscous liquid and then to its final shape, completing the chemical reaction simultaneously. Thus the material constituting the final shape is no longer affected by heat. The phenol formaldehyde resins are available only in dark colors and as rather massive molded articles. To remedy this defect light colored resins of the same composition were developed, but are available only as castings from a liquid and lack the strength and resistance of the molded product.

Later the urea formaldehyde resins were developed as a cross-linked condensation product of urea and formaldehyde. The reaction proceeds much as it does in the case of the phenol formaldehyde resins. It can be stopped in an intermediate stage, yielding a molding powder which can be molded with heat and pressure to a final form which no longer is softened by heat. These products are light colored and rather attractive for many uses. They suffer from the disadvantage that the condensation reaction tends to continue after the molding operation is completed and the molded objects show crazing and embrittlement in course of time. Under many trade names, of which perhaps "Beetle" and "Plaskon" are the best known, these materials are in wide use today.

Recognizing the practical objections to the use of cellulose nitrate, a chemically similar cellulose ester has been developed for use as a commercial plastic; this is cellulose acetate. Cellulose acetate is made from cotton linters by acetylating the free alcohol groups of the cellulose with acetic anhydride, thus benefiting by the big molecular structure provided by nature. In this transformation the properties of cellulose are so altered by the addition of a substantial proportion of acetate groups that the resulting ester possesses the physical characteristics necessary for a plastic material. Under various trade names such as "Tenite" and "Lumarith" cellulose acetate has become one of the most rapidly growing plastic materials. It is thermoplastic, as is Celluloid, and for certain purposes this characteristic gives it an advantage over the thermosetting resins. The attractive light color of cellulose acetate, its

mechanical strength and its stability toward heat and light are great advantages in promoting its use. The rather great amounts of plasticizer required to give it free molding properties and its rather high moisture absorption are disadvantages in certain applications.

Still another type of condensation resin has been developed recently in the form of an ester of a polybasic acid and a polyhydric alcohol. As a polybasic acid is one which has two or more acid groups in the same molecule and a polyhydric alcohol one that has two or more alcohol groups in the same molecule, it is evident that esterification can take place in such a manner as to give a molecule of indefinitely great size. If either the acid or the alcohol has more than two active groups, then a cross-linked molecule may be formed, also of great size, In practice phthalic acid and glycerine are extensively used and the resulting large molecular substance is well adapted to many industrial uses under trade names such as "Glyptal," "Resyl" or "Alkyd." Owing to extreme cross-linking these resins tend to be rather brittle and are commonly modified with softer material, such as unsaturated vegetable acids. In this form the resinous material is particularly well adapted to use as a surface coating or lacquer and most of our automobiles are now decorated with such a finish.

The most recent type of synthetic resins to find an extensive industrial use is the vinyl type which constitutes a rather large group of commercial resins. Any organic chemical compound which contains one unsaturated linkage or olefine group may be considered to be a vinyl compound. Not all of these form resins, but certain of them polymerize rather easily to form large molecular substances. This polymerization is a rather remarkable reaction and is not yet fully explained. However, it is dependable and reproducible on a commercial basis and yields products that could be produced in no other manner. Polymers of vinyl chloride, vinyl acetate, methyl acrylate, methyl methacrylate and of vinyl benzene or styrol, among many others have been proposed for industrial uses. In the aggregate these are consumed to the extent of many millions of pounds each year under trade names such as "Vinylite," "Lucite," "Plexigum" and "Rezoglas." These polymers are all thermoplastic resins, characterized by great

strength and toughness. They are light colored, extremely resistant to water, all reagents and most solvents and certain of them are highly light resistant. A low softening point and lack of color stability in certain ones are their principal unsatisfactory features. No one plastic material can be good for all purposes, but within the vinyl group may be found more attractive and valuable characteristics for industrial purposes than in any of the other types of large molecular substances.

At the same time that work has been progressing on the development of the synthetic solid plastics, there has also been extensive research on the extensible resins or synthetic rubbers. Due to the low cost of natural rubber, there has been little incentive in this country to manufacture a synthetic product for uses where natural rubber will serve. In Germany and in Russia, under government subsidy, a polymerized butadiene is being used for general purposes, although admittedly this would be economically impossible on a strictly competitive basis. In this country, however, three chemically distinct extensible polymers are being manufactured commercially without subsidy for uses where ordinary rubber will not serve. One of these products is a plasticized polyvinyl compound, another is a polymerized chlorbutadiene and the third is a reaction product of organic chlorides with polysulfides. They have special advantages over natural rubber in resistance to oil, gasoline, oxidizing agents and the like and have created new markets for themselves at relatively high prices in spite of the low cost of rubber. For most uses there is little fault to find with ordinary rubber on its technical performance. However, should plant diseases, higher labor cost in the East Indies or any other factor increase the cost of natural rubber materially, synthetic products are known that could take its place on short notice to the complete satisfaction of all users.

INDUSTRIAL APPLICATIONS.

When we come to the industrial applications of these synthetic large molecules, we get far away from the research laboratory and chemical considerations. The users of these materials are principally manufacturers who want a mechanical part to serve a given purpose. The typical specifications are almost all negative, such as that the material shall not

break, shall not soften, shall not discolor, shall be tasteless, odorless and so on. In other words, to be completely satisfactory to the user, the chemist should have done so excellent a job that after its completion the chemical product is thereafter completely inert, as well as being light and strong. Of course no one material can meet all specifications, but of those described all have certain applications in which they are quite satisfactory within commercial limits.

Since plastic materials have been defined as those which may be given any desired shape, and since they are important mechanically rather than chemically, it is perhaps of interest to consider the industrial uses from a mechanical point of view. The simplest mechanical shape is one which has no principal dimension, that is a dust or powder. There are many important uses for powders, but since the synthetic materials are rather expensive and in powder form they have little opportunity to show the valuable mechanical properties that have been built into them, they find almost no ultimate uses in this form. However, in the intermediate processes of fabrication, all of the plastic materials are handled as powders in one or more of the various stages of purification, compounding, and molding.

The next shape is one which has but one principal dimension, that is a filament. For material in this form, provided the right physical characteristics are present, there is an enormous use as rayon, one of the outstanding technical developments of recent years. It is true that viscose rayon, which is made of regenerated cellulose and which I have considered as not being a synthetic material, is the largest single material used as rayon. However, cellulose acetate, a chemically modified cellulose, is growing very rapidly as a rayon material and has many characteristics to recommend it for this use. Also some of the purely synthetic vinyl resins have the requisite properties of strength, toughness, elasticity, chemical resistance and the like which make them suitable for textile uses, where other natural and synthetic fibers are less satisfactory. The condensation resins are not satisfactory for filaments, as they are all cross-linked and therefore are too brittle in small diameters.

A shape with two principal dimensions is called a sheet or film and for these the number of uses increases enormously.

Unsupported sheets of synthetic plastics are found everywhere. The ubiquitous Cellophane is made of viscose or regenerated cellulose and therefore is not synthetic, but much that passes for Cellophane is made of cellulose acetate. The motion picture film which made our motion picture industry possible, is generally made of nitro cellulose, although the safety film of cellulose acetate is growing in use. Safety glass for automobiles which is now a mandatory safety precaution in many of our states is composed of a sandwich of synthetic plastic between two sheets of glass. Cellulose nitrate, cellulose acetate and vinyl resins serve this purpose, for which their toughness and transparency make them particularly well suited. Somewhat thicker sheets either transparent or colored serve another host of uses, such as decorative or instrument panels, phonograph records, radio dials, non-breakable watch crystals, index tabs and so on. Also sheets serve as an intermediate shape in the fabrication of articles to which a third dimension is given. Thus buckles, bag fittings, non-breakable dolls, ping pong balls and a great variety of light articles are stamped from sheets and pressed into their final shape.

Supported films include the whole group of protective and decorative coatings. While the principal tonnage in this use is supplied by natural drying oils, the particularly difficult assignments are met by synthetic resins. Thus insulating varnishes are used extensively in the electrical industry; waterproofing coatings are given to paper for many applications. Automobile and ice box finishes consist mainly of these resins and artificial leather, glazed fabrics and patent leather are other examples of their use in widely separated fields. In such uses, due to the support given to the film, the condensation resins are under no disadvantage and where their other properties are desirable they are freely used.

Shapes with three principal dimensions are those of the ordinary objects we see about us. Of such objects so great a number and variety are made of synthetic plastic materials that the time at our disposal makes it quite impossible for me to do more than indicate roughly where these materials are being used. There are probably very few homes in the country where some of such plastic objects are not found. Pens, pencils, tooth brush handles, clock cases are now commonly

made of these materials. The old time cork stopper was failing to meet the requirements for bottle and jar closures years before the troubled conditions started in Spain which further limited the supply of cork. At present the whole system of closure of packages is being revised and the plastic cap is rapidly taking the place of the once common cork stopper. Control knobs, handles or decorative trim are a part of newer models of all automobiles, telephone receivers, radios, ice boxes, and other household devices. It has been said that any manufacturer who could put his product in the homes of the country has achieved success. By this measure the synthetic plastics industry has been unusually successful, as there is, in addition to the many household articles, a very great industrial application of these resins. In the production of the three dimensional objects from plastics the thermosetting or cross-linked resins have been favored, particularly the phenol formaldehyde and urea formaldehyde resins, because of their strength and shock resistance in fairly thick sections. In many household and industrial uses their permanent hardness when exposed to heat is also a valuable characteristic. However, the thermoplastic resins have distinct advantages too in many uses and they are expanding rapidly in uses where they are practically non-competitive with the other type of resins.

The estimated total volume of synthetic plastic materials for the uses I have attempted to outline is in the neighborhood of two hundred million pounds for the year 1937. While this total is relatively small compared with the tonnage of rubber, cotton and some other natural organic products, it is nevertheless evidently well beyond the laboratory stage. Such volumes of material are not handled in laboratories but in factories. Certain factories are producing raw materials such as phenol, urea, formaldehyde and the like. Others are carrying out the proper condensation and polymerization reactions, compounding the large molecular products with the pigments, fillers and modifying agents to form molding powders. Still others are performing the mechanical operations of molding, calendering, extruding, to give the products their final form. These operations require the assistance of auxiliary industries such as the machine shops and foundries to produce the heavy duty mechanical equipment. Also warehouses, transporta-

tion facilities, distribution and selling of the products are necessary. In other words a substantial industry is in the making and one that has grown phenomenally even during the distressed times that we have suffered from since 1929. It might be said that this new industry is experiencing a boom, resulting from a fortunate combination of important industrial needs for the product combined with successful research in developing superior new products at steadily decreasing costs. Indeed there are many indications of boom conditions in the confusion of literally hundreds of new trade names. Large numbers of new patents are issuing, foreshadowing still other new types of large molecular substances and new applications of the old. As is not unusual under such conditions, over-enthusiasm leads to unwise decisions and perhaps many of the present undertakings in the plastics field may prove to be unsound. However, there is unquestionably much that is good already accomplished and the new plastics industry is here to stay.

PROSPECTIVE DEVELOPMENTS.

When a project has developed to the extent that the plastics industry has under the stimulus of the new synthetic large molecular materials, the question is bound to rise as to how much further it can go. To give a precise answer to such a question involves a gift of prophesy which I do not claim to have, but I do believe that much is known that can throw some light on the future.

Surely these synthetic materials are well adapted for our use, as they are of the same general characteristics as the natural materials that have been chosen for construction of the things about us since earliest times. By this I mean the qualities other than the strictly technical ones, such as softness or smoothness to the touch, lack of thermal shock which characterizes metallic or ceramic products, pleasing color, transparency or translucency, ease of cleaning and resistance to scratching or abrasion. We seem always to have selected such materials from among those available without knowing exactly why and now that they are available in improved form, we will surely keep on using them.

Cost is always an important item affecting wide use of a product and on this point there is definite assurance. Compared with the cost of other chemical products at present the

costs of the new synthetic plastics are somewhat high. This does not mean that manufacturers are making an unjustified profit, but rather that eventual economies have not yet been realized and that the full benefits of mass production are still to come. With time and further increase in scale of production the costs will surely trend downward, which will promote still wider use.

It would be most pessimistic to believe that further technical improvements will not be made, both on the chemical and on the mechanical side of the production of finished plastic products. One difficulty which has existed in most products made up to the present has been the locked up stresses in the finished articles. These stresses have been due to shrinkage in molding and have limited the maximum dimension of the pieces which can be produced successfully without excessive brittleness or warping. During recent years the maximum dimension of commercial products has been increasing consistently due to technical improvements and now small radio cabinets are appearing as single molded pieces. Should this improvement be carried somewhat further, then it will be possible to produce pieces of the size commonly used in the furniture and home construction fields. When this point is reached then there may be expected a very rapid increase in the tonnage of plastic materials consumed. You are, no doubt, all familiar with the discussion of what we are to do when our forests have vanished completely. Well, there is no single answer to such a problem, but it is very sure that in the near future we may expect that plastic materials will be competing with wood very keenly for both decorative and utilitarian applications whether the forests have vanished or not.

It appears then that science has opened another new frontier, more important in many ways than the geographical frontiers that many lament as a thing of the past, To those who can understand the intricacies of this new chemistry, the voyages into this new territory have as much glamor and excitement as could possibly have attended the expeditions of the early explorers. What is most important, instead of opening geographical frontiers for new and unneeded agricultural production, this new chemical territory offers the prospect of creating new economic values, giving useful employment and raising our standards of living.

THE INFLUENCE OF MOISTURE UPON THE D.C. CONDUCTIVITY OF IMPREGNATED PAPER.

BY

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INTRODUCTION.

The generally accepted procedure for measuring the d.-c. resistivity of fibrous insulation is to apply the potential for a period of a few minutes at most and calculate the resistivity from the current flowing at the end of this period. This current is frequently referred to as the leakage current, although it can be demonstrated that when the insulation is reasonably dry more than 90 per cent. of this current does not flow through the dielectric but is slowly reversible.

The purpose of the present paper is to present the results of an investigation carried out for the purpose of discovering how the moisture content of paper influences the relationships between potential gradient, time and current. The importance of these effects rests not only upon their relationship to the mechanism of conduction in fibrous insulating materials but also upon their bearing on the testing and performance of such insulating materials in service.

DESCRIPTION OF SAMPLES.

Because of the high resistivity of well dried cellulose it is desirable that the sample have a high ratio of area to thickness. For this reason the samples selected for this investigation were standard condenser windings each of which consisted of two layers of 0.0004" linen condenser tissue between aluminum foil electrodes. The electrode separation was 0.0024 centimeters and the ratio of area to separation 1.71×10^5 centimeters. The windings were first brought into equilibrium with a relative humidity of 90 per cent. at 35° C. to insure a moisture content throughout higher than the final desired moisture content. This preliminary conditioning re-

quired a period of one month. The windings were then immersed in an impregnating compound (chlorinated naphthalene) at 120° C. The immersed windings were allowed to reach equilibrium with a predetermined external pressure P_1 after which the whole mass was allowed to cool slowly to room temperature. It should be noted that the only factor varied from lot to lot and the variable which determined the final moisture content was P_1. A group of samples of low moisture content was prepared by predrying a set of windings conditioned at 90 per cent. relative humidity by evacuation at 120° C. before impregnation.

After impregnation the samples were pressed to a standard thickness and immediately sealed in small individual cans with chlorinated naphthalene. As a further precaution against change in moisture content these cans were sealed in wax blocks with only the terminals of the samples projecting. While chlorinated naphthalene was used as the impregnating compound in this series of tests our results indicate that the effects discussed are qualitatively similar where other types of impregnant are used.

The moisture contents of the various samples were determined by pumping the water off at 150° C. and a pressure of 1 to 2 millimeters of mercury through a weighing tube filled with phosphorous pentoxide.[1] The moisture contents of the various groups of samples calculated as percentage of the dry weight of paper are given in Table I.

TABLE I.

Impregnation Pressures P_1 in mm. Hg.	Moisture Content Per Cent.*
Pre-dried	0.15
0	1.05
74.5	1.49
375	2.75
670	4.07

* The moisture contents here and throughout this paper are based upon the dry weight of the condenser tissue.

[1] This determination is discussed in a paper now in preparation for publication. It will be noted that the moisture contents given in Table I do not correspond to those taken from the adsorption isotherm at pressures corresponding to P_1. This difference is fully accounted for by the surface tension effects of the impregnating compound as shown in the paper referred to.

EXPERIMENTAL RESULTS.

1. Voltage-Current Relationship.

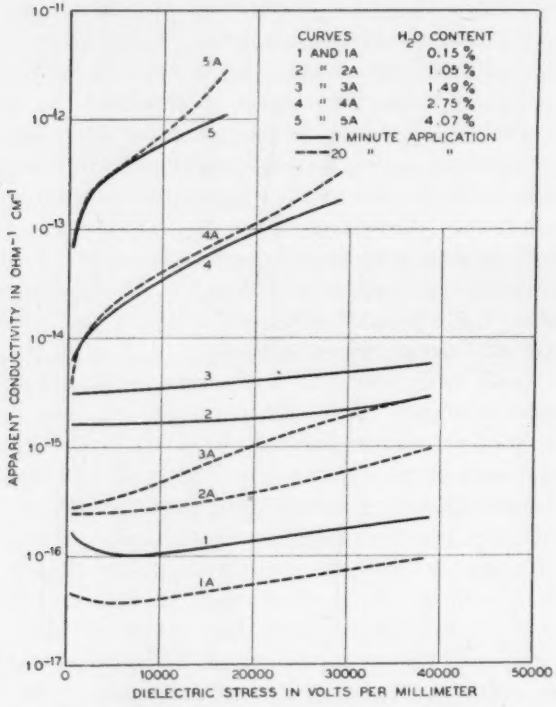
The influence of the potential gradient on conductivity was determined by means of a sensitive galvanometer and source of d.-c. potential. The values of current are expressed as "apparent specific conductivity." In using this term deference is shown the fact that a given value can be reproduced only under identical conditions and hence cannot be considered a constant of the material in the sense in which we are accustomed to using the term conductivity. In addition no attempt has been made to separate the reversible and the irreversible current although some mention will be made of their relative magnitudes under certain conditions.

The relationship between apparent conductivity and testing voltage is shown in Fig. 1. Curves of apparent conductivity against potential are plotted for one minute and twenty minutes application of voltage. At the lowest moisture content the apparent conductivity is relatively independent of dielectric stress although it tends to increase somewhat both with low and with high potential gradients. At moisture contents of 1 per cent. to 1.5 per cent. the conductivity increases slowly but regularly with the increase in potential and more rapidly the higher the potential. At higher values of moisture content the increase in conductivity with potential gradient is much more marked. An important point to be noted is that the one minute values do not increase rapidly with voltage until quite high moisture contents are reached. As a matter of fact, the ratios of the apparent conductivities at the two values of dielectric stress 40,000 and 4,000 volts per mm. are practically the same whether calculated from curves 1, 2 or 3 and would, therefore, be a poor criterion of dryness. Considerable increase in the reliability of such a criterion is obtained, however, by extending the time of application of potential as illustrated in the dashed curves of Fig. 1. By further extension of the time of application to one or two hours the increase in current with voltage may be observed in samples containing 1.05 per cent. water as will be seen by referring to the data discussed in the next section.

The increase in current with voltage at high moisture

contents has been studied by Evershed [2] and is referred to as the Evershed effect. At high moisture contents where liquid water can exist in relatively large pores Evershed has demonstrated that this effect may be explained by the flow of water in isolated pools under the influence of the

FIG. 1.



Apparent conductivity—Dielectric stress relations in impregnated paper of various moisture contents.

applied field causing two or more such pools to join. At the lower humidities where moisture is adsorbed with a considerable evolution of heat this explanation is hardly adequate. An explanation based upon the breakdown of bound ions which appears to explain satisfactorily the observations made in this investigation will be given later in this paper.

[2] Evershed, *I. E. E. Jl.*, **52**, 51 (1913).

The large effect of moisture upon the conductivity of impregnated paper is illustrated by the difference in level of conductivity for samples of different moisture contents shown in Fig. 1. The samples containing 4.07 per cent. moisture have apparent conductivities 10^3 to 10^4 times that of samples containing 0.15 per cent. moisture. The average results for 50 to 60 samples of each moisture content between 1.05 per cent. and 4.07 per cent. follow a curve represented by the equation:

$$\text{I.R.} = 3235 \times 10^{-0.88\ \text{M.C.}},$$

where I.R. is the resistance calculated from the current flowing one minute after the application of 4,170 volts per mm., the samples being at 35° C. M.C. is the moisture content in per cent. by weight. The form of this equation is that given by Walker[3] for cotton between 0 and 3 per cent. M.C. For raw cotton he found an exponent of 1.06 to 1.16 as compared with 0.88 for the samples of impregnated paper studied here. In a recent publication, Walker[4] reports a value of 0.7 for the exponent obtained in studies of rag paper. In Table II values of I.R. calculated from the above equation are compared with the average of observed values at each moisture content.

Table II.

Moisture Content in Per Cent.	I.R. (Megohms) Calculated.	I.R. (Megohms) Observed.
1.05	386	379
1.49	158	158
2.75	12.3	11.5
4.07	0.87	0.93

For 0.15 per cent. moisture content the observed value is much higher than that calculated.

The points to be noted concerning these relationships are:

1. The presence of water in the paper may radically change the voltage current relationship and it is essential that this relationship be understood before measurements of conductivity can be used as an indication of moisture content.

2. The presence of moisture may reverse the direction in which the current changes with time.

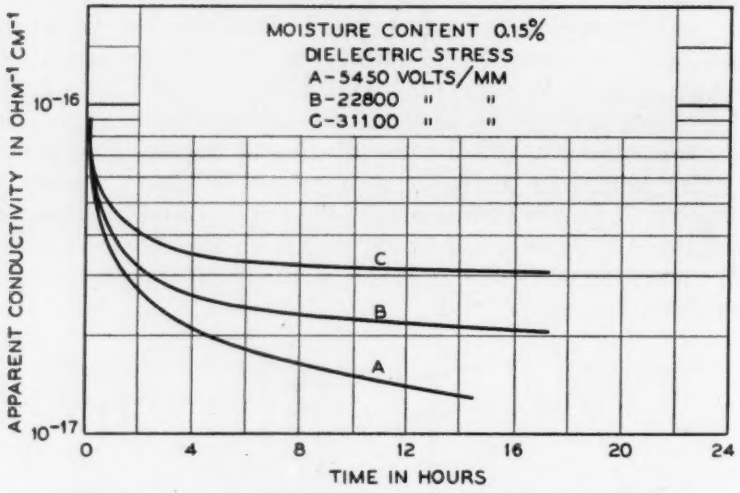
[3] Walker, *Jl. Text. Inst.*, **24**, T145 (1933).

[4] Walker, *Jl. Applied Physics*, **8**, 261 (1937).

CONDUCTIVITY TIME RELATIONS.

For the purpose of studying current time relations at constant voltage an amplifier recorder combination has been constructed. This consists of a Leeds and Northrup recording potentiometer coupled to the plate circuit of a single stage d.-c. amplifier. In the experiments a constant potential was applied to a sample and the current recorded for a period of 16 to 24 hours. A separate sample was used for each test to avoid possible electrical after-effects. All samples were maintained at 35° C. during the entire period of test.

FIG. 2.



Apparent conductivity—Time curves for impregnated paper containing 0.15 per cent. moisture.

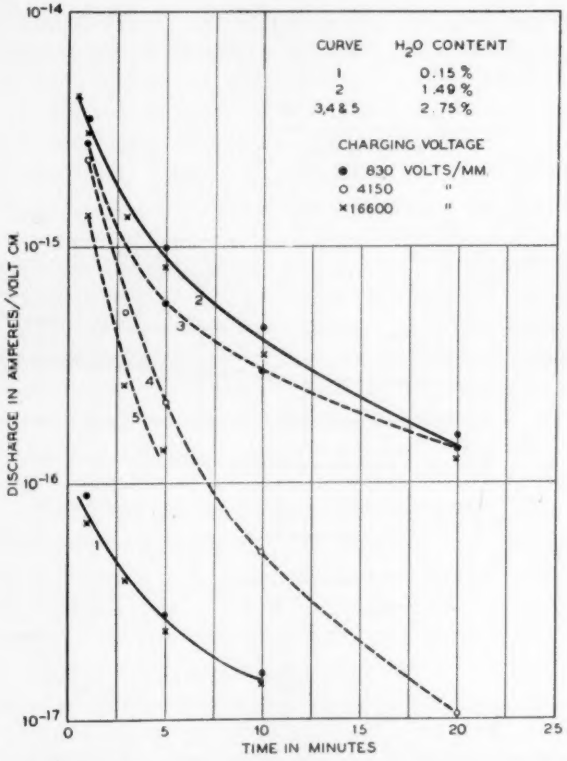
Typical curves for relatively dry samples (0.15 per cent. H_2O) are given in Fig. 2. An outstanding feature of these curves is that the current falls off continually during the application of voltage over a 24-hour period. This type of curve represents the well-known dielectric absorption which has been the subject of much study and comment.[5, 6] Although the rate of change of current diminishes as time goes on, no point is reached where additional changes do not occur.

[5] Whitehead, *A. I. E. E. Jl.*, **45**, 515 (1926).

[6] Whitehead and Marvin, *A. I. E. E. Jl.*, **48**, 186 (1929).

Voltage is seen to have an effect upon these curves, the apparent conductivity tending to increase with increasing voltage. These variations with voltage are small compared with those for samples containing somewhat higher moisture contents. Discharge curves taken over several hours indicate

Fig. 3.



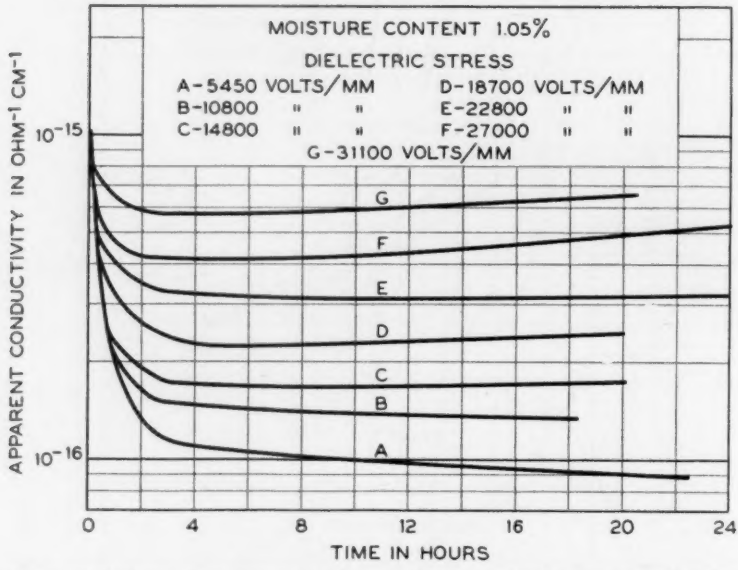
Discharge curves for impregnated paper of various moisture contents after charging for twenty minutes.

that an appreciable part of the initial current in relatively dry samples is reversible. In Fig. 3 are shown discharge curves taken for 20 minutes after a 20-minute period of charging. It is seen that for a relatively dry sample the discharge curve in terms of current per volt of charging potential is independent of the charging potential. These

observations correspond to a picture of polarizations of long relaxation times and could be represented as far as the charge and discharge curves are concerned by a parallel arrangement of capacities in series with resistances as discussed by Murphy and Lowry.[7] This of course may be considered to be in parallel with a resistance representing the true resistance of the dielectric.

When we progress to a study of the current-time relations for samples containing about 1 per cent. of moisture, the

Fig. 4.



Apparent conductivity—Time curves for impregnated paper containing 1.05 per cent. moisture

results shown in Fig. 4 are obtained. Here the current decreases with time over the whole test period at the lowest potentials employed; at higher potentials, it comes to a moderately constant value; and at the highest potential, a slow but definite increase with time occurs. All of these effects are preceded by an initial decrease with time, this being one of the indications that polarization effects are still important.

[7] Murphy and Lowry, *Jl. Phys. Chem.*, **34**, 598 (1930).

The increase of current with time and with voltage at about 1 per cent. moisture content introduces a new feature of the current-time curves, probably closely related to the Evershed effect. Although the initial apparent conductivity at this moisture content is fairly insensitive to the potential gradient (Fig. 1), after a period of hours there is a marked spread between the curves for the various voltages. A large part of the current flowing during the initial decrease is reversible, the static dielectric constant having been markedly increased by the additional moisture. The reversible polarization current for 20 minute periods of charge and discharge is again proportional to the charging voltage.

The important feature of the apparent conductivity-time curves at 1.05 per cent. moisture content is the increase with voltage. The apparent conductivity measured after 5 hours application of voltage, where all of the curves are quite flat, is quite accurately an exponential function of the dielectric stress.

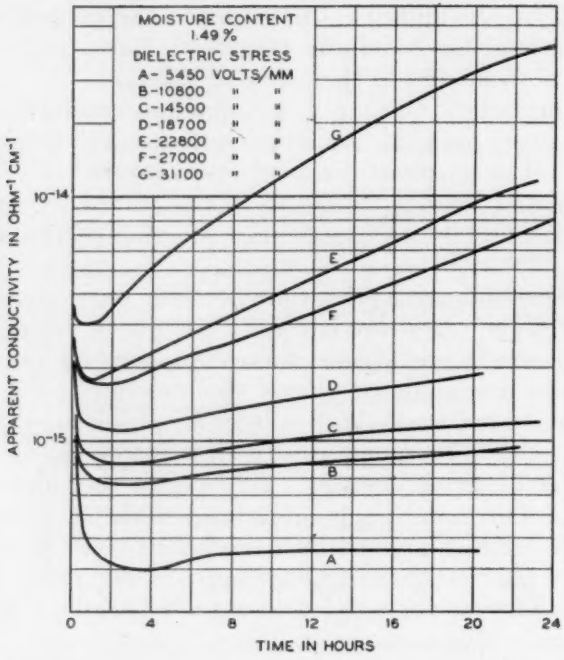
Increase of current with time becomes more important at the next higher moisture content. In Fig. 5 are shown the apparent conductivity-time curves for samples of 1.49 per cent. moisture content. Here the tendency of apparent conductivity to increase with voltage is marked at all potential gradients, while its increase with time is also pronounced at the higher dielectric stresses. Here again, as judged by the discharge currents for 20-minute periods of charge and discharge, quite a large part of the current which flows during the early part of the charging curves is reversible, and the discharge current per volt is at least very nearly independent of voltage. This is shown in Fig. 3.

At the next moisture content, 2.75 per cent., the results of which are shown in Fig. 6, the increase of apparent conductivity with time is much more rapid, and in agreement with the previous results, is more marked the higher the dielectric stress. It should be noted, however, that at quite a low stress, the current remains almost constant over a 24-hour period. In curve *B* of Fig. 6, the first indication of another phenomenon occurs. This is an eventual decrease with time, and will be discussed in more detail later.

The phenomena observed in the intermediate range of

moisture contents studied (1–3 per cent.) appear to be consistent with the theory of dielectric absorption and residual charge proposed by Murphy and Lowry.[7] Although certain effects have been observed in the present study which were not discussed by these authors, particularly an increase in apparent conductivity with time, nothing has been observed which is inconsistent with their theory of polarizations due

FIG. 5.



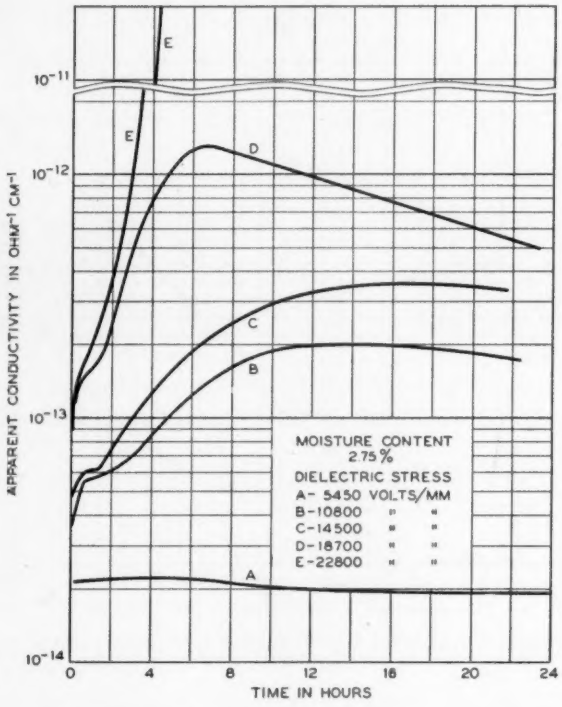
Apparent conductivity—Time curves for impregnated paper containing 1.49 per cent. moisture.

to bound ions. These adsorbed ions would be free to move under the influence of an electric field, but their range would be restricted by adsorption forces.

According to this theory, the polarization currents would be accounted for by the movement of these ions within their restricted ranges to oppose the field. The increase of apparent conductivity with potential gradient would correspond to the breakdown of these polarizations and their conversion into

conducting ions. This latter calls for a decrease in static dielectric constant as the testing voltage is increased. Although the discharge curves do not cover a sufficient period to allow accurate determination of the static dielectric constant by graphical integration, an estimate can be made by extrapolating the curves and adding to the value so

Fig. 6.

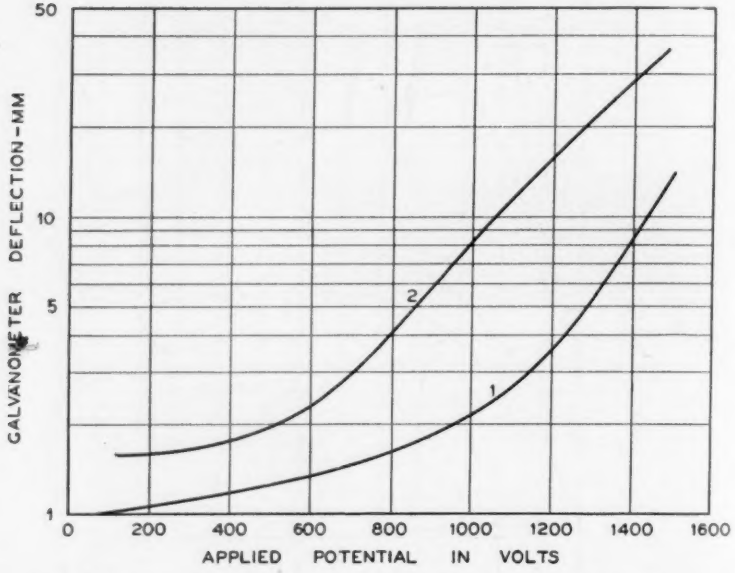


Apparent conductivity—Time curves for impregnated paper containing 2.75 per cent. moisture.

obtained the 1 kilocycle value. For the samples of 0.15 per cent. moisture content, there is thus obtained a static dielectric constant independent of voltage of 6.26 as against 5.93 at 1 kilocycle. As the moisture content increases, the static constant increases until it is 17.7 at 1.49 per cent. moisture content, the 1 kilocycle dielectric constant being 6.7. The two values 6.26 and 17.7 correspond to curves 1 and 2

of Fig. 3. At a higher moisture content, 2.75 per cent., where the increase of apparent conductivity with voltage and time first becomes marked for short times (20 min.) of application of voltage, the static dielectric constant, for comparable times of charge and discharge, first becomes a decreasing function of both voltage and moisture content. This is illustrated by the spread of curves 3, 4 and 5 in Fig. 3. All this would be predicted from the theory of ionic polariza-

FIG. 7.



Apparent conductivity—Voltage curves for a mica surface with adsorbed moisture. 50 laminations in parallel. Electrode separation 0.050". Relative humidity 50 per cent. 1, 35° C. 2, 47° C.

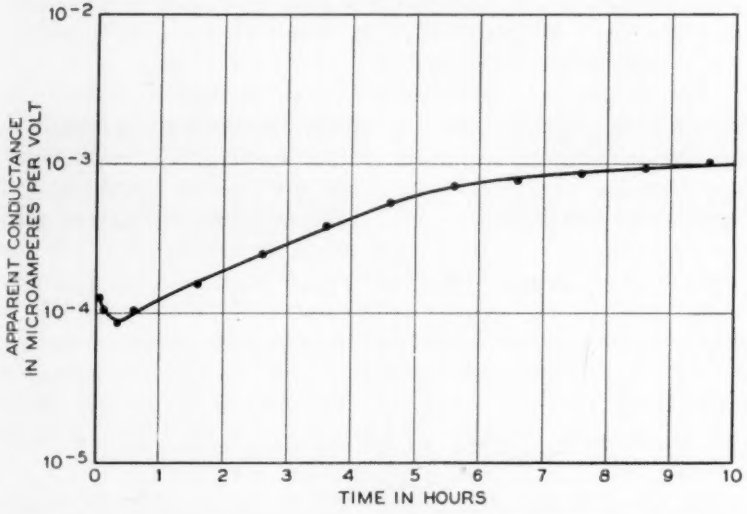
tion on surfaces,[7] and is confirmatory evidence for this type of polarization.

Current-time curves of the type shown here, where the apparent conductivity increases with voltage and with time are not peculiar to cellulosic materials, but may be a rather general property of surfaces on which moisture is adsorbed. Figure 7 shows voltage-apparent conductance curves for a mica surface kept under conditions where it is known to adsorb moisture, while an apparent conductance-time curve

is shown in Fig. 8. The similarity of these curves to several of those for impregnated cellulose will be noted.

Certain of the curves involving an increase in current with time are qualitatively similar, of course, to those which would obtain under conditions of thermal instability caused by joule heating. However, there are several reasons why an explanation based upon thermal instability is untenable. In the sample represented by Curve *F*, Fig. 5, for example, the total current flowing at the end of six hours application of potential

Fig. 8.



Apparent conductance—Time curve for mica surface with adsorbed moisture. Same sample as Fig. 9. Relative humidity 50 per cent. 35° C.

is 2.5 microamperes, sufficient to raise the temperature of the sample less than 0.1° per hour if it were all converted into heat and none of it dissipated to the surroundings. Yet in the following ten hour period, the apparent conductivity is doubled. No such large temperature coefficient of conductivity as would be necessary to explain these curves by the I^2R loss has been observed. If the increase in conductivity were due to electrical losses, the heating effect would vary as E^2/R which would make it, since R decreases with

voltage, a more critical function of the voltage than is actually observed.

Another point of importance in this argument is that one may add impurities to the impregnating compound in sufficient quantities to increase the initial conductivity well above that for the samples represented in Fig. 5, yet as long as care is taken to exclude moisture, the current decreases continuously with time over a period of hours, and may or may not approach a constant value by the end of 24 hours. One need not assume however, that moisture is the only impurity which could produce current increase phenomena, and the similarity of the results reported here to observations on glass into which electrode material has been forced[8] should not be overlooked.

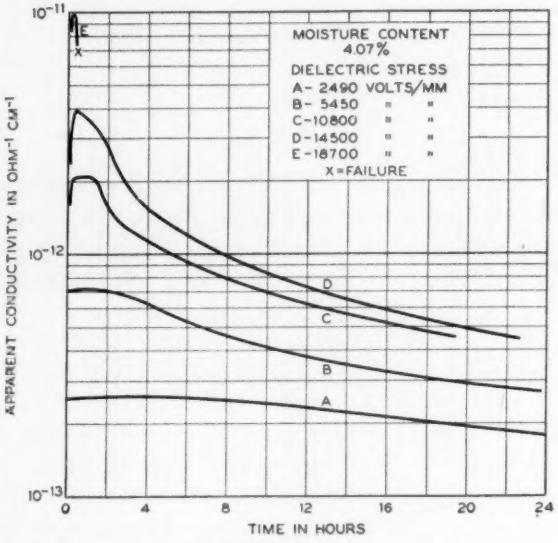
The bearing of these results upon the life on continuous potential of sorbent materials containing moisture is apparent. By the breakdown of ionic polarizations the conductivity may increase to a point where the material is worthless as a dielectric. Furthermore, while the increase of current with time is believed to be a non-thermal phenomenon, it can proceed until thermal instability does occur. This appeared to be true for the sample represented by Curve *E*, Fig. 6, where the current eventually increased more rapidly than the recorder could follow it until complete breakdown occurred. Besides the thermal instability which may be introduced by the breakdown of ionic polarizations, electrolytic processes harmful to the dielectric are probably accelerated.

In the samples of 4.07 per cent. moisture content, results on which are shown in Fig. 9, a factor noted, although in less degree, at 2.75 per cent. moisture content becomes marked. This is an effect opposing the increase in current with time. It eventually overcomes the latter effect, the time required for this to happen decreasing with increasing moisture content and increasing voltage. At 4.07 per cent. moisture content any initial decrease of current with time is not detectable on the time scale used. That is, as the moisture content and voltage are increased, the minimum in the curve moves to the left until it vanishes.

[8] Kiehl, Physics, **5**, 370 (1934).

No exactly comparable samples of higher moisture content were available for test. However, the trend of type of curve with moisture content and voltage invites the prediction that at high enough moisture contents and voltage gradients, the current would decrease from the beginning of the test, or at least that the portions of the curves representing an increase with time would be forced out of reach of our time scale.

Fig. 9.



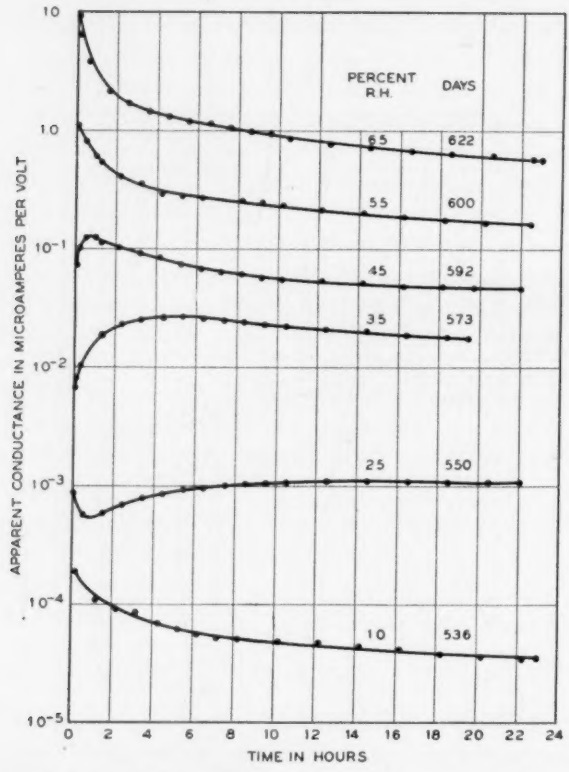
Apparent conductivity—Time curves for impregnated paper containing 4.07 per cent. moisture

This prediction is confirmed by results on a slightly different type of sample. Samples were dried and impregnated and then exposed to various relative humidities from 10 per cent. to 65 per cent. for approximately 1½ years. In this way it was possible to get sufficient moisture into the outer layers of the samples to control the electrical behavior to a large extent. In Fig. 10, it is seen that at high relative humidities the current does decrease with time over the whole period. At lower humidities the curves develop through all of the types discussed above. Fig. 10, as a matter of fact, provides a very good picture of the evolution

of type of curve from low to high moisture contents, the potential gradient being constant.

The descending type of current-time curve at high moisture contents has been attributed to the formation of

FIG. 10.



Apparent conductance—Time curves for samples exposed to various relative humidities. Figures represent relative humidity and period of exposure before test. Potential gradient = 10,800 volts/mm.

high resistance regions in the neighborhood of the electrodes.[9, 10] Such a picture corresponds to our ideas of what is happening in these samples at high moisture contents. This idea is substantiated to some extent by a critical de-

[9] Murphy, *Jl. Phys. Chem.*, **33**, 509 (1929).

[10] Baker and James, *Physics*, **2**, 73 (1932).

pendence of the current-time curves in this range upon electrode material. Even under conditions where the initial part of the curves is ascending with time, the electrode material is, as one might expect, important in determining how low the current can be kept by this opposing effect, and how soon after application of potential the current will begin to decrease with time.

An important point to be noted is that, under conditions of high moisture content where the current is decreasing with time, complete dielectric failure is not usually preceded by any gradual rise in current, but comes with explosive suddenness. A typical case is that of Curve *E*, Fig. 9, where the failure came while the current was decreasing rapidly with time.

SUMMARY.

Data are presented showing the dependence of apparent d.-c. conductivity upon moisture content, potential gradient and time of application of potential. Three regions of moisture content in which the type of behavior differs are noted. At low moisture contents (below 1 per cent.) a steady decrease in current with time occurs ascribed to polarizations of long relaxation time. In this region approximately 90 per cent. of the current flowing at the end of one minute is reversible and therefore is not a true leakage current. The apparent conductivity is dependent upon voltage, there being a tendency for it to increase somewhat with increasing voltage.

At higher moisture contents (1–3 per cent.) the increase of apparent conductivity with time and voltage is marked. At still higher moisture contents (above 3 per cent.) a third region is encountered where the predominant phenomenon is a current which decreases with time and is probably caused by the building up of high resistance regions in the vicinity of the electrodes. These three types of behavior have vague boundaries and the characteristics of more than one of them can usually be detected in a single current time curve. Furthermore, these boundaries shift with the applied potential, an increase in voltage having an effect similar to an increase in moisture content.

It is shown that the increase in current with voltage and with time sometimes referred to as the Evershed effect may

be observed at low moisture contents and on crystal surfaces containing adsorbed moisture. It is concluded that this is a rather general phenomenon observable when moisture is adsorbed on surfaces, and that it is unlikely that the explanation for the effect at high moisture contents proposed by Evershed based upon the movement of the liquid water in pools under the influence of the applied field is applicable to the case of moisture strongly adsorbed on surfaces at low humidities.

It is shown that the observed phenomena are consistent with the theory of dielectric adsorption and residual charge proposed by Murphy and Lowry. The increase in current with voltage and with time is accounted for by the breakdown of ionic polarizations of long relaxation times to form free ions which then contribute to the conductance current.

Under certain conditions, the breakdown of bound ions into free ions proceeds until the conduction is sufficiently high to produce thermal effects. For this and other reasons which are discussed the results have an important bearing on the electrical breakdown of fibrous insulating materials under continuous potential.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

PARKING METERS.

At the request of the Director of Vehicles and Traffic of the District of Columbia, the Bureau has made an examination of parking meters. In all, 19 meters, the products of 11 manufacturers, were tested as time-measuring instruments, and for possible defects in mechanical construction. In connection with the work, a large amount of data on the use of these meters was collected. A complete report was made to the Director of Vehicles and Traffic last month, and it is understood that practical experiments with parking meters in service will soon be inaugurated in Washington.

PRESSURE LOSSES IN PIPE BENDS.

In even the simplest piping system, the pipes must change direction in many places. Therefore, bends, and particularly 90-degree bends, are perhaps the most frequently used fittings. As pressure losses in bends are greater than in the same lengths of straight pipe, the effect of a number of bends in a pipe line is to decrease the flow. To obtain a given flow, it is necessary to increase the pipe diameter or to provide more pumping capacity, either of which expedients increases the expense of the installation.

Many experiments have been made to find the exact pressure losses in pipe bends, but the results seem to be very inconsistent. A paper by K. Hilding Beij in the July *Journal of Research* (RP1110) describes an investigation which forms part of a general program under way at the National Hydraulic Laboratory, to determine the reasons for these inconsistencies, with the ultimate object of developing, if possible, reliable formulas for computing pressure losses in pipe bends.

The experiments concern 90-degree pipe bends in 4-inch pipe lines. Tests were made on bends varying from 6 to 80

* Communicated by the Director.

inches in radius. It was found, for bends having a radius of four times the pipe diameter or less, that the results could be brought into agreement with those made by previous experimenters under comparable conditions, provided the roughness of the pipe walls was taken into account. More work was needed, however, to determine the exact relationships, and hence a working formula.

For bends of radius greater than four times the pipe diameter it was found that other unknown, and as yet unpredictable, effects obscure the problem. Until this problem is solved, the designer must use the experimental results which indicate the highest pressure loss in order to be certain that the pipe capacity will be sufficient.

UNDERGROUND CORROSION AT INDUSTRIAL PLANTS.

Differences in the electrical potentials of two areas on the same pipe or on two connected pipes may arise from many causes. These result in electric currents which remove metal from one of the areas. Differences of potential are so prevalent that they can be found almost anywhere if a sufficiently sensitive instrument is used. The problem of the corrosion engineer is to determine the significance of these differences of potential.

Corrosion may be the result of stray current electrolysis, segregations in metals, or corrosive soil conditions. Electrolysis is usually confined to the neighborhood of street-car tracks and substations, and can be identified by the fluctuating nature of the currents flowing on the corroding structure. Corrosion caused by inferior materials is comparatively rare.

If the above possible causes are eliminated it is safe to assume that observed corrosion is due to soil conditions without testing the soil.

Electrolysis may be reduced by the use of insulating joints or by lowering the potential of the corroding structure below that of the surrounding earth.

Soil corrosion may be reduced by the use of corrosion-resistant metals. These must be selected with respect to the soil conditions they will encounter.

Reinforced bituminous coatings properly applied will also reduce corrosion. It is difficult, however, to apply and maintain a perfect coating.

Corrosion at the imperfections in coatings may be prevented by connecting the corroding metal to the negative side of a source of low potential direct current, and connecting the positive side to a set of suitably placed electrodes. This is known as cathodic protection.

STRAY CURRENTS IN BUILDINGS.

At the spring meeting of the American Research Committee on Grounding, the technical subcommittee submitted a progress report to the representatives of the 14 National organizations including the Bureau which are coöperating in this movement. The report covered six additional field investigations and several sets of laboratory tests.

In one of the six cases investigated no trouble was reported—the investigation having been made because in the construction of a large building the electrical isolation of all protective grounds from the piping systems had been attempted. Electrical tests and inspection showed, however, that such isolation had not been attained.

In the second case reported, the complaint was of leaky water-pipe joints, and the trouble was apparently due to a combination of high water pressure and poor workmanship in the original installation.

In another case where the complaint was of a failure of boiler tubes, steady readings of small direct current were obtained at the boiler, indicating galvanic action. On the pipes and grounding conductor close to the service entrance the readings were small and fluctuating, indicating stray electric-railway currents.

In the three remaining cases the complaints were of discoloration, or other impairment of the quality of the water delivered through taps on customers' premises. Of these three cases one showed no electric current present on the pipes, another was cleared up by lime treatment of the water, and the third case was remedied by reducing the temperature of the hot water to 140°.

To date the technical subcommittee has investigated some 26 field cases where complaints have been made, and where it was suspected that stray alternating or direct current might have been a factor in producing the trouble. In none of the cases so far investigated, however, has the trouble been found to be due to alternating current on the water-piping system, although on the other hand, investigations have not shown that such current may not have contributed to the cause of the complaint in some of the cases. A number of significant factors have been found, including the tendency of the water in question to corrode the piping or other metal, the effect of dissimilar metals in the piping system creating galvanic couples, and corrosion of hot-water supply boilers due to abnormally high temperatures. Further field investigations are to be made as cases are reported to the committee by water companies where troubles such as corrosion, impairment of water, sparking, or electrical shock are suspected as being caused by electrical grounding.

Field work is being supplemented by laboratory investigations of the fundamental electro-chemical principles involved. It is believed that these will throw considerable light on the causes of the water companies' difficulties.

Laboratory tests on samples of metals simulating pipes have been made. These tests have indicated many factors that enter the problem of the effects of superimposed alternating current on galvanic-cell current, and further tests to determine the fundamentals involved are being undertaken.

HYDROGEN-REDUCTION METHOD FOR THE DETERMINATION OF OXYGEN IN STEEL.

The report of the recent coöperative study of methods for the determination of oxygen in steel, sponsored jointly by the Bureau and the American Institute of Mining and Metallurgical Engineers, has shown the need for further intensive study of some of the methods in order that their accuracy and limitations may be definitely specified. To extend the data on one of these methods a study was made, by John G. Thompson and Vernon C. F. Holm of the Bureau's Metallurgy Division, of the Brower, Larsen, and Shenk modification of the hydrogen-reduction method. As reported in the *Journal*

of Research for July (RP1114), it was found that the method yielded accurate values for the total oxygen content of several plain carbon steels, including steels that contained small amounts of alumina and silica, but yielded low results when larger amounts of alumina were present. The method was not applicable to the determination of the oxygen content of open hearth iron because of inability to separate surface and body oxygen in this material.

DETERMINATIONS OF OXYGEN IN ALLOY STEELS.

The results of the recent international coöperative study, referred to in the preceding item, defined the accuracy and limitations of the methods in common use for the determination of oxygen in simple steels. However, information on the applicability of these methods to the analysis of alloy steels has not been available heretofore. The determination of oxygen is a difficult problem, even in simple steels, because of the number of oxide compounds and combinations. The analysis of alloy steels involves additional uncertainties because of the probable presence of oxides of the alloying elements that are not in simple steels.

In reporting on recent work in the Bureau's Division of Metallurgy (RP1115 in the July *Journal of Research*), J. G. Thompson and V. C. F. Holm conclude that accurate determinations of the total oxygen content of many alloy steels can be made either by the vacuum-fusion method or by a modified hydrogen-reduction method. The limitations of both methods are essentially the same for alloy steels as for simple steels. The common alloying elements or their oxides do not present added difficulty in the operation of either method.

DETERMINATION OF ARSENIC, ANTIMONY AND TIN.

An improved method for the determination of arsenic, antimony and tin, developed by John A. Scherrer of the Chemistry Division, is described in the *Journal of Research* for July (RP1116). In the new procedure arsenic, antimony and tin are separated from most of the lead in babbitts, type metals, solders, and the like by digestion in hydrofluoric,

nitric, and sulfuric acids, and from most of the copper, zinc, lead, etc., in brasses and bronzes by digestion in nitric acid, or precipitation by ammonium hydroxide after solution in aqua regia. The three elements are then converted to sulfates, the arsenic and antimony reduced to the trivalent state, and the three then separated by fractional distillation and determined by titration. The results for antimony and tin obtained by this method are more accurate than those obtained by so called direct titration methods. Since the method provides for the isolation of these elements, positive identification of very small amounts of these constituents is facilitated.

DETERMINATION OF ALUMINUM IN NONFERROUS MATERIALS.

Since the presence of aluminum, even in very small amounts, is harmful in certain types of bearing metals, solders, and zinc alloys, it is important to have an accurate method for its determination in such materials. Ammonium aurintricarboxylate is used for this purpose, but existing methods are complicated and uncertain. An improved method for the use of this well-known reagent has been developed by John A. Scherrer and William D. Mogerman of the Bureau's Chemistry Division, and is described in RP1117 which will appear in the *Journal of Research* for July. The new method is simple and reliable and consists essentially in subjecting a sulphate solution of the alloy to a preliminary electrolysis in a mercury cathode cell to remove interfering elements, and then testing the electrolyte with ammonium aurintricarboxylate. The pink color so produced is compared with standards prepared in the same way.

PREPARATION OF AMMONIUM AURINTRICARBOXYLATE.

Very small amounts of aluminum have deleterious effects on many types of nonferrous alloys. In some brasses and bronzes it reduces the ductility, increases brittleness, and in other ways acts unfavorably. In a large number of bearing metals, solders, and zinc alloys the American Society for Testing Materials limits the amount of aluminum to less than 0.005 per cent. For the reliable performance of the method

for the detection and determination of small amounts of aluminum referred to in the preceding item, a dye of uniform and high quality must be available. As a suitable reagent could not be obtained either by purchase or preparation by procedures described in the literature, a method was devised by John A. Scherrer and W. Harold Smith for the preparation of the ammonium salt of aurintricarboxylate acid, which is satisfactory for use in the test for aluminum. RP1118 in the July *Journal of Research* should be consulted for the complete report on this work.

ACCELERATED AGING OF LEATHER IN THE OXYGEN BOMB.

For the last two years Joseph R. Kanagy of the Bureau's leather section has been investigating the behavior of leather in an oxygen bomb in order to obtain data to be used in developing an accelerated aging test. Such a test is important in the development of leathers for long service as, for example, bookbindings and upholstery leathers. It would also improve testing and save time in research.

The results of a previous investigation were published in Technical News Bulletin 242 (June, 1937). In that study samples of chestnut- or quebracho-tanned leather were dried in an oven at 100° C. for 24 hours and then exposed in the bomb to an atmosphere of oxygen initially at 100 lb./in.^{2} and aged at 100° C. for 7 days. The results compared favorably with those obtained when similar leathers were aged under normal conditions for 10 years. The present investigation is a continuation of this study. Rawhide and various tannages of leather were exposed in the oxygen bomb under the conditions mentioned above. The amounts of carbon dioxide and water evolved from some of the leathers and rawhide, when heated in a stream of oxygen at 100° C., were also determined, and these results for the vegetable-tanned leathers were related to their stabilities in the oxygen bomb.

The results indicate that such factors as stability of the tannins to oxidation, tanning properties of the tanning materials, and conditions which weaken the hide substance during the tanning process, are reflected in the results obtained

in the oxygen bomb. The mechanism of the deterioration occurring in the bomb also appears to be similar to that occurring under normal aging conditions. For these reasons, it is concluded that aging under the accelerated conditions in the oxygen bomb should give valuable indications as to the aging properties of a leather.

PERMEABILITY OF WRAPPING MATERIALS.

Wrapping and packaging materials impervious to moisture are demanded for many purposes, including protection of food products and other hygroscopic articles of commerce. It is, therefore, important to have adequate testing methods for determining whether or not a material is sufficiently resistant to the passage of moisture to serve a given purpose.

A contribution has recently been made by F. T. Carson of the Bureau's paper section, toward the improvement of test methods for determining permeability to water vapor. A simple and effective way has been devised for affixing a specimen to a dish or permeability cell using equipment commonly found in the laboratory, or that can be easily improvised. The specimen is sealed to the cell in a positive manner by means of wax, and by the use of a templet the area to be exposed is made definite and clear-cut. The method is adaptable to various forms of dishes and cells, and allows the specimen to be sealed in at any desired height in the cell, thus eliminating certain common errors.

THE FRANKLIN INSTITUTE

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is thirty-five cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon. 569 readers made use of the facilities during the twenty-six days of June.

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BOOK REVIEWS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 624, Two-Dimensional Subsonic Compressible Flow Past Elliptic Cylinders, by Carl Kaplan. 8 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

The method of Poggi is used to calculate, for perfect fluids, the effect of compressibility upon the flow on the surface of an elliptic cylinder at zero angle of attack and with no circulation. The result is expressed in a closed form and represents a rigorous determination of the velocity of the fluid at the surface of the obstacle insofar as the second approximation is concerned.

Comparison is made with Hooker's treatment of the same problem according to the method of Janzen and Rayleigh and it is found that, for thick elliptic cylinders, the two methods agree very well. The labor of computation is, moreover, considerably reduced by the present solution.

The third approximation to the compressible flow about circular cylinders, including the terms involving the factor $(v_0/c_0)^4$, is also obtained and compared

with the result given by Poggi. It is found that the expression given by Poggi is incomplete with regard to the terms containing the factor $(v_0/c_0)^4$.

Report No. 625, A Discussion of Certain Problems Connected with the Design of Hulls of Flying Boats and the Use of General Test Data, by Walter S. Diehl. 8 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

A survey of the problems encountered in applying general test data to the design of flying-boat hulls. It is shown how basic design features may be readily determined from special plots of test data. A study of the effect of the size of a flying boat on the probable limits to be covered by the general test data is included and recommendations for special tests and new methods of presenting test data for direct use in design are given.

EVERYDAY THINGS IN AMERICAN LIFE, 1607–1776, by William Chauncy Langdon. 353 pages, illustrations, plates, 16 × 23 cms. New York, Charles Scribner's Sons, 1938. Price $3.00.

There is a continual stream of visitors throughout the year to historic shrines, places where historic events took place or places that indicate to some degree the life and associations of the early settlers and colonists. Likewise, novels based on historic events of the early years of white settlements in this country have become extremely popular, being read by thousands. To many, these visitations and readings do not merely constitute pastimes but they create a genuine interest in the everyday difficulties of the life of people of preceding generations. Such interest makes for greater appreciation of our present day advantages. There is, however, a very important point that is only too often lost sight of and this is very ably brought out in Everyday Things in American Life. Much of what is to be seen today is not truly indicative of average life and conditions. The first settlers arriving on these shores built temporary shelters which were abandoned when substituted by more permanent structures, therefore there is no evidence now in existence. As to the later structures covering the entire first 150 years of settlement, only those of very substantial construction remain. These are the work of the more wealthy or are places of community business, hence do not very well reflect life as it was to the average or lower classes who after all were the backbone of the early settlements. Many things, other than structures do remain, however, and from these together with the writings of those who lived at the time, the author of this book has endeavored to give the reader a knowledge of life as it was.

The book covers the period 1607 to 1776 from the settlements in Virginia up through Pennsylvania, New York, and into New England. As time went on the territory included the interior to the Allegheny Mountains and to Albany. There does not seem to be any particular plan of the book, each topic being taken up and thoroughly discussed before another is examined. The apparent random choice of topics no doubt was limited by the material available. The architecture and construction of homes and public buildings, metals and the manufacture of useful implements, ship construction, commerce, communication, furniture, and education are some of the things discussed.

Undoubtedly the author has made considerable research and study to obtain the mass of information here presented. The book is not merely a statement of

fact. It is so interwoven with stories in connection with the topic that it should be popular reading. At times it is really delightful and gives the reader a sense of satisfaction in being interested while accumulating a very useful and appreciative knowledge.

A comprehensive subject index in the back of the book gives it added value as a reference work.

R. H. OPPERMANN.

ON UNDERSTANDING PHYSICS, by W. H. Watson. 141 pages, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $2.25.

The rapid progress in scientific research in recent years has resulted not only in certain satisfactory confirmations but has added the irritation of creating new and unexplained problems. The constant groping for truth is sure to be helped by a recognition of the value of philosophy and with this in mind, the author offers this work which is based on developments in modern philosophy, largely due to Dr. Ludwig Wittgenstein. It is not a report of Dr. Wittgenstein's lectures, being only the reflection of the author himself which bears evidence of the influence of them, however. On the one hand the discussion here recorded proposes to interest physicists in philosophy in the Wittgenstein sense, and on the other an attempt is made to show its value for clarifying physics—especially mechanics. There are discussed discipline in philosophy, logic and psychology and physics, methods of representation, the nature of mechanism, the logic of substance and motion, and some aspects of the symbolism of mechanics and electricity.

Some of the logical problems are taken up, that have been thrown into prominence during the development of atomic mechanics. The treatment here differs from that to be found in the writings of mathematical physicists and others who have dealt with them. The author contends that these matters should be regarded as logical problems and whether the analysis is complete or not will show itself in the same way as correctness or error in a mathematical theory, but of course the use of language is a more complicated affair than mathematics.

R. H. OPPERMANN.

MASTER BUILDERS OF SIXTY CENTURIES, by John Anderson Miller. 315 pages, illustrations, 14 × 21 cms. New York, D. Appleton-Century Company, 1938. Price $3.00.

Travelers over the world often encounter works or structures built by the ancients that have a general appeal. This appeal is primarily because of age. Seldom does it extend to recognition of engineering achievements that today would seem almost unsurmountable when considering the materials, tools and facilities that were available during the period of construction. The machine age has brought with it, among other things, speed in construction. Not the mere halving of time which has been more or less commonplace in the present generation but much more than that. For an example take such articles as nails or mortar and reflect on time as an element in construction without their use. The chipping of stone without hard metals which are available today is another example. A long list may easily be compiled which will reveal the patience and genius of engineers of by-gone eras.

The author of Master Builders of Sixty Centuries has attempted to bring historic feats of engineering into focus with what engineers are doing today. In accomplishing this there are accounts given of achievements such as the construction of the Great Pyramid at Ghizeh where one hundred thousand workmen labored for twenty years using bronze saws and tubular drills; how the Greeks built stone walls without mortar and the basis of Doric and Ionic architecture; the Great Wall of China, work on which involved the equivalent of the efforts of a quarter of a million men for a hundred years; the Roman water supply system; the mystery cities of the Mayas; and others.

The book is a series of clearly written, interesting and informative chapters. In the foreword the author states that it "is not a history of engineering, nor a statistical analysis of famous structures, but simply an informal account of certain particularly interesting engineering achievements, presented from the standpoint of making them better understood by the average man."

R. H. OPPERMANN.

THE FINE STRUCTURE OF MATTER, THE BEARING OF RECENT WORK ON CRYSTAL STRUCTURE, POLARIZATION AND LINE SPECTRA, being Volume II of a comprehensive treatise of atomic and molecular structure, by C. H. Douglas Clark. Part II: Molecular Polarization. 232 pages, illustrations. Part III: The Quantum Theory and Line Spectra. 256 pages, illustrations, 15 × 22 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.50 each.

The first part of Volume II of this series of books, devoted to X-rays and the structure of matter, was reviewed in the May 1938 number of the Journal of The Franklin Institute. In continuation of this work Part II is devoted to molecular polarization. It begins with a statement of the general theory on the dielectric constants of gases and then proceeds into a more detailed treatment of the constants of pure liquids, mixtures, solutions, and liquid crystals; concluding with the dielectric constants of solids. The results recorded here consist of an array of experimental facts which appear largely uncoordinated. It is shown that dielectric constants are less important theoretically than the corresponding molecular polarizations.

The Debye theory of polarization, a treatment of which follows, is one of the leading themes of the book. Others are the derivation and meaning of dipole moments and Fajan's theory of deformation. Related matter necessary for carrying out this plan is covered in adequate detail. A brief review of methods which have been found useful in considering the problem of various force-fields operating between molecules follows a detailed account of work on the Kerr Effect and dipoles. Polarization phenomena are presented as taking their place alongside the other main avenues of approach in providing valuable information about the structure and stereochemistry of organic and inorganic compounds.

The Quantum Theory and Line Spectra is the title of Part III of the series of books. This has special reference to the newer adaptations of the quantum theory but no attempt is made to deal with the mathematical treatment of the mechanics except that there is indicated where this method has achieved results bearing on items of discussion. After the general principles of line spectra are discussed, attention is directed to problems raised by the fine spectral lines observed using a high degree of resolution. This excludes the "hyperfine" structure of lines which is

reserved for a later volume. The concluding chapter treats on line spectra and the periodic classification.

Both Part II and Part III of the series are page numbered consecutively with Part I. The same plan and method is also carried through. The researches recorded cover a wide range and certainly the task of correlation is greatly facilitated. As an example it is possible to compare spectroscopic results on given substances or groups of compounds with corresponding work on crystal structure and dipole moments.

R. H. OPPERMANN.

THE STORY OF VITAMIN B_1, compiled by C. R. Addinall. 55 pages, illustrations, 21 × 28 cms. Rahway, N. J. Merck & Co. Inc., 1937.

It has only been in recent years that scientific investigation has resulted in knowledge of the importance of vitamins in diet. Such diseases as scurvy, rickets, beriberi and pellagra are widely spread and well known, and there is now a definite recognition of the part played by vitamins as physiological essentials, not only in connection with these diseases alone but in others. Indeed, mere failing health may be a cumulative result of deficiencies in the diet.

This brochure of some 55 pages contains a review of recent literature. The review together with information presented from various standard sources gives a comprehensive treatment. It is divided into seven parts, viz.: The isolation and synthesis of vitamin B_1; Its properties and standards; Its assay and units; Physiology of vitamin B_1; Diet and nutrition; Manifestations and therapy in deficiency; Animal nutrition. There is a bibliography noted and a subject index.

R. H. OPPERMANN.

PORTRAITS OF EMINENT MATHEMATICIANS, by David Eugene Smith. Portfolio II, 13 portraits, unpaged, 26 × 35 cms. New York, Scripta Mathematica, 1938. Price $3.00.

This portfolio contains the portraits of thirteen eminent mathematicians whose contributions to the subject have been of particular note. In a folder, together with each portrait, there is contained a biography of sufficient length and of such composition as to furnish an inspiration to all who are interested. The portfolio contains Euclid, Cardan, Kepler, Fermat, Pascal, Euler, Laplace, Cauchy, Jacobi, Hamilton, Cayley, Chebishef, and Poincaré. Many of these names are almost unknown in this present-day world although their contributions to mathematics are used continuously. The average worker in scientific subjects is too little informed with regard to the work of such great men or the romance in connection with mathematics. A perusal of the contents of this portfolio is a good starting point for an accumulation of that which makes for greater appreciation and culture.

R. H. OPPERMANN.

EDWARD WILSON: NATURE-LOVER, By George Seaver. 221 pages, illustrations, plates, 14 × 23 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $3.00.

Many great scientists, in their early years, have found an urge to study science because of their interest in and curiosity about nature. Such a man was Edward

Wilson, who from boyhood took great delight in observing the work of nature. "Edward Wilson of the Antarctic" was the title of a book reviewed on these pages some months ago wherein there was given quite an account of his early life leading through his life at college to the polar expeditions for which he is famous. The present book in comparison details to a greater extent Wilson's work as a naturalist and artist. He is probably popularly less known in this field of endeavor although his contributions are of equal importance.

Like its predecessor this book is composed in part of Wilson's diaries and letters. In these there is revealed the personality of the man which is interesting and inspiring. His power of description is that of a master and his profound devotion to nature showed an appreciation excelled by none. The reader can actually hear the songs of birds and experience with Wilson the joys and adventure of a nature lover. The book covers rural England, Norway and the countries visited on the way to the South Pole. Illustrations both by sketch and color, made by Wilson of birds, flowers and scenery, combine the work of an artist with keen powers of observation. The number of these is too few. The method of presentation and plan of the book add much to making it of value in furthering the appreciation of nature loving readers.

R. H. OPPERMANN.

APPLIED THERMODYNAMICS, by Virgil Moring Faires. 374 pages, illustrations, 15 × 23 cms. New York, The Macmillan Company, 1938. Price $3.90.

The science of thermodynamics has ramifications which extend into many fields including chemistry, electricity and astronomy. Every phase of engineering contains some of the principles of thermodynamics so that for the educated engineer the subject is of paramount importance. How necessary, then, it is to carefully chose a text of fundamentals on this subject. Such a work must be prepared not only with the background of close familiarity with all parts of the subject but the experience of teaching and sympathy with the situation of the student. The book at hand may be considered modern in this respect. The author is professor of mechanical engineering at the Agricultural and Mechanical College of Texas. His work here is of college grade and it is arranged so that there is allowed a choice of those aspects of the subject which are particularly appropriate for a given group of students. Certain chapters may be covered or not, according to the situation of the student. Another feature of special note is the care taken in the proper use of words and terms such as heat, work, available energy, etc.

The text begins with giving simple conceptions concerning the transformations, transfer, and storage of energy, and the first law of thermodynamics after which the energy equations of a perfect gas are discussed. Typical throughout the book are suggestions well illustrated in the chapter on perfect gas equations where the value of graphical presentation of processes is pointed out and encouragement is given to cultivate assiduously the knack of sketching processes on some convenient plane. Next, in logical order, is taken up the laws and characteristics of various thermodynamic processes which furnish knowledge of the relations between pressure, volume, and temperature during any process, the amount of heat transferred, the work done, the values of the changes in internal energy, enthalpy, and entropy. These give foundation for an understanding of the thermodynamic cycles which follow. Included in this are the Carnot and Ericsson

cycles, entropy and the second law, and chapters on cycles and performance information of internal combustion engines. Compression and expansion of air is a subject the discussion of which gives results applicable to any gas, and in part to the compression of vapors.

Other topics covered include steady flow processes and devices for gases, combustion and its products, variable specific heats, processes of vapors, the steam power plant, vapors and gases, refrigeration, and the transfer of heat.

The treatment is well done, giving sufficient details in explaining how heat is converted into useful work or power and how, by appropriate processes of heat transfer and transformation, refrigeration or cooling effect may be obtained.

R. H. OPPERMANN.

PROBLEMS ON APPLIED THERMODYNAMICS, by Virgil Moring Faires and Alexander V. Brewer. 137 pages, tables, diagrams, 15 × 23 cms. New York, The Macmillan Company, 1938. Price $1.40.

This book contains some twelve hundred problems designed especially for use with the text Applied Thermodynamics (reviewed above). The problems are divided similar to the chapters of the text and are carefully compounded so as to enable the student to apply as much of the text material as possible. The answers accompany the problems. Appendices give characteristic constants for gases, saturated steam temperature table, superheated tables as well as ammonia, freon, sulphur dioxide, and mollier diagram for CO_2.

R. H. OPPERMANN.

MAN IN A CHEMICAL WORLD, by A. Cressy Morrison. 292 pages, plates, illustrations, 17 × 23 cms. New York, Charles Scribner's Sons, 1937. Price $3.00.

Three years ago the American Chemical Society celebrated the three hundredth anniversary of the founding of chemical industries in America, with the largest chemical meeting ever held. The New York Section of this great scientific society, through its Tercentenary Committee, included in its continuing program the publication of a book, to be written in language that any intelligent person could understand, that would interpret the vital service of the chemical industries in everyday life in terms of human experience.

Man in a Chemical World is that book. It certainly fulfills the purpose for which it was written. The author paints a vivid picture that brings home to the reader a reminder of the dependency of all living things upon each other, and that chemistry covers all the conditions of life and is intimately connected with every act of every human being. The reader is taken through the part that chemistry plays in industry, the practical science from which man has developed his own methods, patterned after natural prototypes but often going far beyond them, of converting available materials into forms more useful than any Nature provides. The part that chemistry plays in maintaining health is discussed, followed by its contribution to agriculture and foodstuffs, to methods of transportation, to communication by words and transmission of pictures, to those needs of everyday life which are essential parts of modern civilization including clothing and housing. Truly the chemical industry is one that we could ill afford to do without or to have restricted. The story brings to mind the potentialities

of the saying "Water is seldom appreciated until the well runs dry." The book goes a long way in furnishing that which is needed for appreciation.

One of the most important services of chemical manufacture is the function of supplying special materials to all other branches of industry. A few of these services are brought into small compass and observed. Chemistry also is too often thought of as a basis upon which destruction of life and property in warfare is accomplished. The story very quickly and definitely shows that the industry is in no sense a fomentor of strife, but rather its whole activity is bent toward precisely the opposite objectives. The potential causes of international irritation, those of the possession of world monopolies of certain essential raw materials, are constantly being nullified by the activities of the chemical industry in the substitution of the materials or the creation of synthetic products.

The book is an admirable exposition. It is well planned and well written giving past and present achievements in a color that should create inspiration and ambition. It makes enjoyable reading which broadens general knowledge, thereby adding materially to culture.

R. H. OPPERMANN.

INTRODUCTION TO COLLEGE PHYSICS, by Clinton Maury Kilby. Second Edition, 398 pages, illustrations, 14 × 22 cms. New York, D. Van Nostrand Company, Inc., 1938. Price $3.25.

Quite often there occurs the need for a text on physics that is not lengthy to the extent of being preparatory for a thorough treatment which requires two or three years for completion. To meet this need the author presents this work which is of first year college grade, brief and yet giving sufficient knowledge to furnish the proper foundation for further study. It must be recognized that to produce a work which must of necessity be, in a sense, in the abstract, covering the essential points with clarity and avoiding omissions, is a most difficult task requiring the knowledge of a master as well as long experience as a teacher. Such a work, too, is subject to considerable criticism, especially from those using it for giving instruction, as to its fitness for their particular purpose.

Undoubtedly the author meets the requirements to produce this book, and an examination of it reveals an unusually sympathetic and understanding attitude of the situation of the student. The book is divided into five parts, after an introductory section which is general in nature, discussing energy and matter, and the physical units. Mechanics, sound, heat, magnetism and electricity, and light are the parts of the book in the order given. Approaches to the topics are also somewhat unusual. While most texts begin with matter which is easily absorbed and then proceed to the more difficult, the present work seems to disregard this rule in many places. The theory of the author is that fresh minds are more capable of coping with difficulties than later when mental laziness may set in.

The book contains sufficient illustrations and diagrams to adequately supplement the text. At the end of each chapter well composed problems with answers are given. Many solved illustrative problems are given in the text, a feature which makes for assistance in difficult places. A subject index completes a work that should be considered by everyone desiring a not too involved treatment on the elements of the subject.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Everyday Things in American Life, 1607–1776, by William Chauncy Langdon. 353 pages, illustrations, plates, 16 × 24 cms. New York, Charles Scribner's Sons, 1938. Price $3.00.

Survey of Physical Science for College Students, by Paul McCorkle. 471 pages, plates, illustrations, 15 × 22 cms. Philadelphia, P. Blakiston's Son and Co., Inc., 1938. Price $2.75.

Eclipses of the Sun and Moon, by Sir Frank Dyson and R. v. d. R. Woolley. 150 pages, plates, illustrations, 16 × 24 cms. Oxford, Clarendon Press, 1937. Price $5.00.

Physik für Studierende an Technischen Hochschulen und Universitäten, von Ingenieur Dr. Paul Wessel, herausgegeben von Dr. V. Riederer von Paar. 514 pages, illustrations, 13 × 21 cms. Munich, Ernst Reinhardt, 1938.

Soilless Growth of Plants, Use of Nutrient Solutions, Water, Sand, Cinder, etc., by Carleton Ellis and Miller W. Swaney. 155 pages, plates, illustrations, 15 × 24 cms. New York, Reinhold Publishing Corporation, 1938. Price $2.75.

Radio, A Study of First Principles, by Elmer E. Burns. Third Edition. 293 pages, plates, illustrations, 14 × 20 cms. New York, D. Van Nostrand Company, Inc. Price $2.00.

Chemical Kinetics, by Farrington Daniels. 273 pages, illustrations, 16 × 24 cms. Ithaca, Cornell University Press, 1938. Price $3.25.

Astronomy, A Textbook for University and College Students, by Robert H. Baker. Third Edition. 527 pages, plates, illustrations, 15 × 24 cms. New York, D. Van Nostrand Company, Inc. Price $3.75.

The Ringstrom Three Dimensional System of the Atoms and The Theory of Atomic Integration, by Adolph Bernadotte Ringstrom. 87 pages, illustrations, 17 × 25 cms. Chicago, Vega Publishing Company.

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10 cents. Forestry Branch. Lumber Distribution & Consumption in Canada and The United States, 1936. 27 pages, 22 × 28 cms. Price 25 cents. Ottawa, Minister of Trade and Cqmmerce, 1938.

Bell Telephone System, Monographs: B-1067, Loudness, Masking and their Relation to Hearing and Noise Measurement, by Harvey Fletcher. 47 pages, illustrations. B-1069, Variable Equalizers, by H. W. Bode. 16 pages, illustrations, B-1070, Studies of Telephone Line Wire Spacing Problems, by J. A. Carr and F. V. Haskell. 36 pages, illustrations. B-1071, Radioactivity—Artificial and Natural, by Karl K. Darrow. 27 pages, illustrations. 4 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1938.

CURRENT TOPICS

Phase Modulation.—A new method of radio transmission and reception, which indicates that international broadcasts of the future will be transmitted over greater distances with four times the output of transmitters of present ratings, was described before the convention of the Institute of Radio Engineers by M. G. Crosby of RCA laboratories. Application of the method would make possible an even closer linking of nations and empires by voice than is now possible. Described by Mr. Crosby, whose work on the development covers ten years of research, as a system of "phase modulation," the new method makes possible greatly increased power at the transmitter, which results in a reduction of the annoying effects of static, man-made interference, and fading. One of the chief advantages of the new system, Mr. Crosby said, is to be realizable in either an increased power output for a given amount of transmitting equipment or a reduced amount of equipment for a given amount of power output. This fact holds promise for use in mobile craft communication such as airplane-to-ground transmission where the weight and space required must be small. It is not believed the new system will affect broadcasting on the standard frequency bands, because the most effective reception of phase modulated waves requires receivers especially designed for the system. As for the system's use in connection with television, the only statement that could be made at present would have to be speculative. It might show promise in solving some of the problems of television relaying. The receiver has the advantage of "exalting" the carrier wave and thereby substantially lessening the familiar distortion known as "selective" fading which is always present in some degree in all today's long-distance shortwave reception. The receiver, which is no more complicated than the average present-day broadcast receiver with automatic frequency control, is also capable of receiving the present amplitude modulated waves with the same distortion lessened. The new system conveys a radio signal of constant, maximum strength. Variation or modulation of the new waves is accomplished by shifting the electrical oscillations so that they either precede or lag in their normal frequency of occurrence.

R. H. O.

Hydrocarbons Converted to Fuel Gas by New Process.—J. A. GUYER (*Chemical and Metallurgical Engineering*, Vol. 45, No. 6).

Fuel gas can now be tailor-made to fit individual plant or domestic heating requirements. A new process developed and patented by the Phillips Petroleum Co. makes available fuel gases of definite specific gravity and heating value which may be varied over a wide range. The HWG (hydrocarbon water gas) process combines two fundamental reactions: thermal decomposition of hydrocarbon gases or vapors, and water gas reactions between hydrocarbons and steam. Thermal decomposition reactions have been extensively studied and are used commercially to produce olefins, other hydrocarbons, hydrogen, and carbon. Water gas reactions between hydrocarbon vapors and steam have also been studied extensively, primarily for the purpose of producing low specific gravity gas to blend with natural gas or to produce a controlled B.t.u. value water gas for city distribution. Patents on the HWG process cover a novel form of catalyst, method of operation and operating conditions whereby these two reactions are carried on simultaneously in a high temperature furnace under definitely controlled conditions. The furnace is of modern type radiant heat tube design, similar to those used to crack petroleum. Water is preheated by heat exchangers and waste heat boilers. The other raw material, hydrocarbon gases and vapors, after careful metering and pressure regulating, is led into the steam pipe at the point of entry to the furnace. Upon passing over the catalyst this mixture of vapors is converted to HWG gas which is then led through a waste heat boiler, a cooler and a water separator into the gas main. Plants of this design can be built having capacities from 2,000 to 200,000 cu. ft. per hour. A wide variation in raw material is possible, such as propane, butane, and other hydrocarbons found in refinery vapors.

R. H. O.

Oil-Burning Locomotive Makes Long Trip Without Change.—(*The Oil and Gas Journal*, Vol. 37, No. 7.) An oil-burning steam locomotive recently established what is believed to be the longest continuous run by a steam locomotive in regular passenger service. An engine of the Atchison, Topeka & Santa Fe Railroad made the 2,227 mile run from Los Angeles to Chicago at an average speed of 45 miles an hour. Ordinarily this train requires four locomotive changes. The route includes some of the steepest grades on any railroad in this country. By the use of oil-burning engines the railroads are meeting modern demands for increased speeds. Fast-burning and efficient fuel oils and automatic lubrication are important factors in the new high-speed engines. Realizing this trend, the petroleum industry has developed new types of fuel oil to meet the railroads' needs. More than 55,000,000 bbls. of these

oils, available in different grades, are used by the railroads every year. More than 6,000 oil-burning locomotives, including diesel electrics, are powered by petroleum. The development of automatic lubrication for locomotives is an outgrowth of the swing toward longer runs. Locomotives equipped with mechanical lubricators need less terminal servicing. Special lubricants keep the engines running smoothly at climatic temperatures which may vary over a range of 100 degrees on a single trip.

R. H. O.

Non-Slip Safety Metal.—(*Railway Age*, Vol. 105, No. 1.) The American Brake Shoe and Foundry Company is now manufacturing an improved type of non-slip safety metal which is said to be highly resistant to rust and acid corrosion, and unaffected in its non-slip properties by water, oil and other slippery liquid substances. In the manufacture of this metal, electric furnace abrasive grains are applied to cast iron, bronze, aluminum or nickel silver, by a special process of casting. By this process the grains are said to be deeply and uniformly bonded into the metal at the time of casting, thus forming what is claimed to be a virtually indestructible bond between the abrasive grains and the metal. The grains protrude sufficiently above the surface to give a "bite" to the metal. The method of manufacturing makes it possible to assure a wear and corrosion resistant "nose" to stair treads, as the abrasive grains are carried entirely over the "nose" and concentrated at this slipping point. The sluffing out and loss of abrasive grains due to corrosion along the "nose" are prevented by this method, as no grinding is necessary to remove raw fins of metal on the casting ridge.

R. H. O.

Oil Free Compressed Air.—(*Power Plant Engineering*, Vol. XLII, No. 7.) Removal of oil from compressed air to give a standard of purity demanded by certain industrial applications is practically impossible. To take care of such conditions and requirements, Sulzer Bros. of Switzerland have recently developed a reciprocating compressor designed for operation without cylinder lubrication. This compressor is of vertical type with the piston rod and piston carefully balanced to eliminate lateral deflection. The piston rod is fitted with a crosshead and the piston is guided by a vertical tail rod. By this arrangement the distance between the piston and the cylinder can be reduced to a minimum without danger of contact. In addition the piston is covered with anti-friction metal in which circular grooves are cut to form a labyrinth

to retard the passage or leakage of air. The tightness is said to be equal to that obtained with piston rings. Stuffing box lubrication has been eliminated by using a compressed carbon made up of annular segments shaped so that there is no direct rubbing contact with the rod. Tightness, as in the cylinder, is obtained by the throttling effect. The cylinder itself is made of special rustless cast-iron to eliminate any possibility of rust from moisture contained in the air. For the crankshaft and tail rod the lubricating systems are designed so that the oil cannot possibly find its way into the cylinder. The crankcase, the lower part of which forms a sump for the circulating oil, is closed at the top above the crosshead by a stuffing box as is the lower end of the tail rod. Although a compressor of this type is slightly more expensive than a normal compressor with lubricated cylinder, the power savings over a rotary compressor which would be used to obtain the same compression ratio are considerable. The energy at full load may be only 8 per cent in favor of the reciprocating machine, but the energy requirement at low load or average load may be well over 50 per cent.

R. H. O.

Highest Multiple Arch Dam.—In *Engineering News Record*, Vol. 121, No. 1, the features of Bartlett Dam are described. This is now being built fifty-four miles north of Phoenix, Arizona. It is on the Verde River and is a multiple arch concrete dam higher than any previous structure of its rather uncommon type, and as modern is design and construction as present developments in the art can make it. The dam will rise 287 feet above its foundations to impound 201,500 acre-ft. of seasonal flood waters in a 3170 acre reservoir for release to the lands of the Salt River Valley irrigation project. In selecting a multiple arch for the Bartlett site, the Bureau of Reclamation chose a type of design with which it had had little previous experience but which careful investigation indicated was the most suitable and economical to meet the conditions. The multiple arch dam, in fact, is not a common type, authoritative records listing only about 30 such structures in the world that exceed 100 ft. in height. Only three of these rise above 200 ft.—Castrola, Italy, 226 ft.; Tirso, Italy, 239 ft.; and Lake Pleasant, Arizona, 256 ft. Bartlett Dam, with a height of 287 ft., will thus be at the head of select company. Multiple arch dams, moreover, have not enjoyed continuous popularity. Although the first such dam (Meer Alum in India) dates from over 100 years ago, it was not until about 1900 that one with a height of 100 ft. was constructed. In the next 25 years only four other " major " dams (over 100 ft. in height)

were built, all in the United States. The decade 1920–30, however, recorded a world wide sweep in popularity, and 23 major multiple arch dams were constructed. Then another lull occurred and, in the current decade, only three multiple arch dams have been added. One of these, the 145 ft. Hamilton Dam in Texas was finished last year, so that, with the completion of Bartlett in 1939, there will be witnessed another small revival of interest.

R. H. O.

Phanotron Rectifiers as a D-C Supply for Elevator Motors.—C. C. CLYMER AND R. G. LORRAINE. (*Electrical Engineering*, Vol. 57, No. 7.) There are a number of public utilities that have instituted programs for curtailing and in some cases completely eliminating direct current power supply to concentrated load areas. The change from direct to alternating current power supply for elevators in the affected areas requires the substitution of alternating current elevator equipment or the use of converters to supply direct current to existing equipment. Where a converter is to be used, a phanotron rectifier possesses many advantages. It is of particular interest as it is the first industrial application of the modern type of metal electron tube in power sizes. The phanotron tube used in the elevator type of rectifier is of the directly heated hot cathode type, with a metal envelope, internal insulated anode, and mercury vapor. It is designed to operate at condensed mercury temperatures of from 20 to 80 degrees centigrade. The average expected life of this type of tube is 10,000 hours. The rectifier design includes six tubes, anode contactors, thermal overload relays, and reclosing timers, all mounted and conveniently enclosed. Triple single phase phanotron rectifiers at the present time are built in capacities up to 40 kw. at 230 volts and 75 kw. at 550 volts. Their application is not at all restricted to elevator loads. Among the advantages are the first cost is competitive with other forms of converters, there are no rotating parts so no special foundations are required, quietness in operation, greater efficiency than a motor generator set, and semi-automatic operation thus requiring little attention.

R. H. O.

Chemical Treating of Surfaces, New Principle in Lubrication.—A. L. FOSTER. (*National Petroleum News*, Vol. XXX, No. 26.) The addition to suitably refined mineral oils of chemicals to impart to the oil the property of maintaining a film on a bearing at higher pressures than can be supported by mineral oil alone is a widely adopted practice. Now an entirely new method of attack has been developed on the Pacific Coast, by an oil company, on the problems

in connection with the lubrication of friction surfaces which have arisen through the developments in automotive engines in recent years. It came to notice at the recent meeting of the S. A. E. The Feritex process, as the new development is called, was worked out in the laboratories of Standard Oil Co. of California, by chemists and metallurgists of that staff. The process is merely that of treating the steel of the surface of cylinder walls, rings, pins, crank bearings, or any surface exposed to pressures and requiring lubrication efficiency, in a solution of chemicals for a predetermined time under predetermined temperatures, then cleaning the treated surface, and oiling. The principle involved is that of removing selectively certain constituents of the steel, such as ferrite, to a desirable depth, forming a highly polished surface without irregularity, but one which is covered with a network of microscopic pits, grooves and slits, still preserving the even level of the main portion of the finished and polished surface. The lubricant is retained in the "hollows," and supports the working parts to a degree unknown in any other method except when using extreme pressure lubricants. According to G. L. Neely, lubrication technologist of the California company, the chemical solution—the composition of which has not been disclosed—does not affect the heat treatment or properties of the metal obtained by heat treatment, but attacks the surface, without affecting tolerances or manufacturing limits set by the requirements of the product.

R. H. O.

New Cooling Experiments in London Subways.—(*Heating and Ventilating*, Vol. 35, No. 7.) Two interesting experiments are being made by the London Passenger Transport Board with a view to controlling further the temperatures of the London subways. They are at Trafalgar Square and Tottenham Court Road stations. At the former, apparatus is being installed to inject water vapor into the station, the theory being that the vapor will absorb heat and the cooled air will be forced along the tunnel by trains travelling to the next station. At Tottenham Road station which connects the city with the northern suburbs, a large refrigerator is being installed in a disused elevator shaft to circulate cold fluid through a system of pipe grids. Electric fans behind the grids will blow cool air into the system.

R. H. O.